Evaluating Security of Energy Supply in the EU: Implications for project appraisal

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Table of Contents

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Executive summary

The security of energy supply has been a crucial issue for all EU Member States due to their dependence on imported fossil fuels in the energy mix. There is general agreement in the international literature about the nature of the impacts of a lack of energy security, affirming that it can be classified under the category of economic externalities: the cost of a disruption in supply and of a dramatic price increase—two events that have macroeconomic consequences and are not internalised by consumers and investors in their decisions. The available literature does not provide a clear methodology for computing these externalities. Quantifying costs of the security of energy supply would assist public and private investment decisions, internalising the implications of a lack of energy security and helping to rank investment priorities in a more rigorous and efficient manner. The purpose of this paper is to propose a methodology to assess the costs of security of supply or, in other words, to quantify the costs of any action that can counteract the damage to the welfare of society caused by a lack of security of supply. It also discusses the optimal cost level of the actions to increase energy security, and presents some results.

In line with the vast literature addressing the security of supply of energy; it is proposed to define economic losses caused by a lack of energy security as the cost due to either a partial or total disruption of supply (supply curtailment, demand/supply unbalances) or a sharp and abrupt price increase (price shock). According to this definition, the economic concept of energy security encompasses the physical dimension i.e. the availability, reliability and adequacy of energy supply, and the pricing dimension i.e. the affordability and reasonableness of market-determined prices. The two dimensions are clearly intertwined. Even if the dimensions are closely linked and, in principle, it can be considered that the market is always able to bring demand and supply in balance through price signals, our first important methodological assumption is that, in some instances, the physical problem must be treated separately. There are at least two cases when this happens. The first one is when the price response is limited (for example for institutional reasons) or too slow to bring supply and demand back into balance. The second one is when there is a limited physical transfer capacity so that, if there is a supply shortage in the market under consideration, a specific price would prevail in that market making the internal price no longer equal to the international price – a typical congestion situation. Addressing the price risk and assessing what could be done to tackle the problem better requires three different conceptual steps. Firstly, the loss incurred by society because of an energy price shock must be assessed. Secondly, the various tools to limit the losses incurred and their costs must be identified. And lastly the willingness to pay to limit the potential damage must be evaluated.

The main purpose of this research is to provide a tool for the assessment of the cost of security of energy supply, comprising a physical availability component and a pricing component. As regards

the concern of physical unavailability, we consider that the society is averse to this risk and is ready to pay in order that the N-1 principle is always complied with. This means that in all circumstances the interruption of one source of supply should be unable to prevent the market from reaching equilibrium without quantity rationing (the extreme case being complete supply interruption) or price differentiation. If this does not occur, one has to pay to restore this condition. Practically, in a project appraisal, the capacity of the energy system to cope with unexpected events assessing its ability to meet the security of supply standard based on the N-1 rule must be evaluated. This is particularly relevant, for instance, for gas infrastructure projects and for supply contracts that can be transacted through one only specific infrastructure. We verify whether the infrastructure condition is satisfied and what the expected contribution of a new energy project to achieve this standard would be. If the rule is satisfied and remains so even after the new project then we conclude that this cost has already been internalised. If not, the least cost solution must be identified and that cost of meeting the N-1 standard should be added to the project under appraisal. It may also happen that the rule is satisfied only when a new project is implemented; in this case, this would indicate positive externalities. As regards the price shock consequences, we first identify the potential damage caused by a price spike to an importing country. This damage is evaluated through the loss of GDP caused by an increase in the costs of imports, and in the case of gas, depends on the price increase, the gas demand elasticity, and the share of the value of gas imports to GDP. The tools to manage the risk of damage range from stimulating internal production, building national storage or buying an insurance against price increases in the financial markets, for instance, a call option. We conclude that the latter is the cheapest and in many cases the easiest solution. Concerning the evaluation of the willingness to pay in order to avoid the price shock damages there are many methods based on stated or revealed preferences.

In conclusion, the contribution of this study to the analysis of security of supply is twofold. Firstly, it presents a method to evaluate the externalities associated with security of energy supply and what has to be done to internalise them, taking into account the two equally important constituent parts of energy security: physical availability and price. The focus is on natural gas, as it is the fuel that presents by far the largest costs of supply security. This assessment can help establish energy policies that incorporate the objective of energy security more consistently and coherently with other objectives. Secondly, the method proposed by this study is useful for the evaluation and comparison of different energy projects since risks and impacts of a lack of energy security differ among Member States, given the divergence in terms of energy mix, availability of domestic energy resources, substitution possibilities, storage, infrastructure adequacy, and reliance on energy imports.

1. Definition of security of energy supply

Since the Green Paper "For a European Union energy policy" presented by the European Commission in 1995 the security of energy supply has been, together with competitiveness and environmental protection, one of the three pillars of the EU's energy policy. In fact, even before the model of the three pillars became the reference, energy security had always been one of the fundamental objectives of the EU. And the same is true of all energy-importing countries. Nevertheless, there is no commonly shared definition of security of energy supply. If there is no definition that makes this variable measurable, it is difficult to establish an energy policy based on various measures that can increase security of supply. Therefore, we should start by specifying precisely what we mean by security of supply.

Within policy documents addressing the energy security concern, probably the most widely used definition is the one provided by the International Energy Agency, as the availability of an *"adequate supply of energy at a reasonable cost"* (IEA, 1985, p. 29). The European Commission's Green Paper "Towards a European strategy for the security of energy supply" (EC, 2000) takes a similar approach and states: *"The EU's long-term strategy for energy supply security must be geared to ensuring […] the uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers […]".*

According to these definitions, from an economic standpoint the concept of energy security encompasses the **physical dimension**, i.e. the availability, reliability and adequacy of energy supply and the related infrastructure, and the **pricing dimension**, i.e. the affordability and reasonableness of market-determined prices.

The importance of these two dimensions within the definition of energy security has been frequently confirmed in the literature. For instance, Bohi and Toman (1996, p. 1) point out that the lack of energy security refers to *"the loss of economic welfare that may occur as a result of a change in the price or availability of energy"*. Scheepers and Seebregt (2007, p. 19) relate a security supply risk *"to a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies"*. More recently, Loschel et al. (2010, p. 1668) claim that *"security of energy supply exists if at least current volumes of energy are available in the short and medium term at prices which do not significantly exceed past medium-term price-trend levels"*.

In addition to the requirements of physical availability and the affordability of energy prices, some studies include additional constraints when defining energy security. The most common is the requirement of *acceptability*, i.e. to be secure, energy supply should be not only available and affordable, but should also respect environmental sustainability concerns (Kruyt et al., 2009). The European Commission's Green Paper asserts that energy supply security *"must be geared to ensuring, for the well-being of its citizens and the proper functioning of the economy, the uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial), while respecting environmental concerns and looking towards sustainable development"*. Likewise, the Asia Pacific Energy Research Centre (APERC, 2007, p. 6) defines *"energy security as the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy"*. Whilst Chevalier (2006, p. 2) suggests that energy security *"is a flow of energy supply to meet demand in a manner and at a price level that does not disrupt the course of the economy in an environmentally sustainable manner"*. Finally, the dimensions of availability, affordability and sustainability are also pointed out by the United Nations Development Programme (UNDP, 2004, p. 42), which defines energy security as *"the availability of energy at all times in various forms, in sufficient quantities and at affordable prices without unacceptable or irreversible impact on the environment"*.

The literature review highlights that definitions of energy security share a number of features. In addition to those mentioned above, the first is that security of supply is perceived as some sort of cost/risk judgement, defining security of supply in terms of a risk-management strategy. A second and tied feature is that, although the security of supply concerns first governments, it is a shared responsibility among governments, firms and customers that goes beyond 'command and control' and towards the allocation of tasks among stakeholders. Another commonality is that security of supply has two equally important constituent parts requiring the management of a physical issue (ensuring supply) and doing so at a reasonable cost and without any sudden price spike.

The two dimensions of the problem are inextricably linked and only partially distinguishable. The physical disruption of supply can result in a sudden spike in price. A price shock can be seen as the equivalent of a supply disruption even when is caused by a demand increase that cannot be satisfied at the previous price.

To assume that the market is always able to bring supply and demand in balance through price signals is to ignore the timing of the adjustment or that the adjustment may occur at an unacceptable level. Our assumption is that the two dimensions can be treated separately, i.e. that we can prevent lack of supply at a given price and price increases above a certain level at a given demand.

2. Physical availability component of energy security

The physical dimension of security of supply becomes evident when energy supply is either rationed or interrupted. In these cases, the market is no longer able to perform its function of balancing supply and demand either because the time needed to reduce demand through a price signal is too long compared to sudden physical flow reduction or because the price level that should be reached is not deemed acceptable for social reasons.

In the following paragraphs, the focus will be on the risks related to energy supply as well as the likelihood of their occurrence and their possible consequences.

2.1. Security of supply analysis

By definition, the risk associated with an event is the product of the probability of occurrence of that event times its consequences. In our case, the event is whatever can cause a partial or total interruption of a source of energy supply and the physical consequence is the amount of energy supply that is interrupted.

Supply can be disrupted either because the normal operation of the existing supply capacity is interrupted or because the existing supply capacity is unable to meet demand. In the first case we have a *continuity* of supply problem. In the second case there is an *adequacy* of supply problem.

The adequacy of supply is a long term problem because it requires that the investments to maintain the *supply chain* (production, transport and transformation infrastructures) are adequately sized to ensure a supply capacity large enough to meet demand during forecast normal conditions. If supply capacity is adequate, then the continuity of supply is a short term problem and concerns the ability to face adverse events such as technical failures, extreme weather conditions, terrorist attacks, strikes, etc. Obviously, adequacy and continuity are not completely separated. If at any time the installed capacity is not enough to meet the demand, there is a problem of supply continuity.

When studying the risk of supply curtailment, the concept of the supply chain comes into play.

The supply chain consists of all activities ranging from the production/extraction of raw materials to the delivery of the desired product by the final consumer. The more elements in the supply chain the higher the risk that some element may not work properly and that the supply becomes limited if parallel paths are not available. When final consumers use primary energy sources (such as gas or coal) the supply chain is composed of production and transportation facilities, including ships. When using secondary energy sources (such as oil products) or energy carriers (such as electricity or heat), the supply chain includes transformation plants and distribution facilities such as internal grids.

The supply chain can be interrupted at any of its links, which may be due to an accident (e.g. a natural disaster) or may be the result of a deliberate choice (e.g. a terrorist attack or a governmental/corporate decision). It could occur within or outside the consuming country subject to security of supply risk. In the former case it is easier to intervene to restore the continuity of supply. Individuals and governments are usually more concerned with intentional disruptions because it is more difficult to deal with them.

It is not easy to identify and classify all the events that can lead to a supply shortage. In general, from the point of view of governments, external events caused by decisions of other governments or companies outside of their control are of greater concern; imports deserve more attention than internal energy supplies.

Another way to classify the risks of energy supply is as follows:

- Geological risks refer to the possible exhaustion of an energy source and the cost of extraction
- Technical risks include system failure due to weather or obsolescence and poor maintenance of the energy system.
- Economic risks indicate imbalances between demand and supply due to the lack of investment and insufficient supply contracts.
- Geopolitical risks concern potential government decisions to suspend deliveries because of deliberate policies, war, civil strife, terrorism, or as a result of failed regulation.
- Environmental risks depend on the potential damage from accidents (oil spills, nuclear accidents) or pollution such as greenhouse gases emissions that may lead to a supply limitation.

In what follows, we provide an overview of the major threats relating to the supply chain of different energy sources and carriers for EU.

- Oil availability is crucial for the EU. Its use is concentrated in road, maritime and air transport and then to some extent in the industrial sector. Oil use for power generation has declined since 1990 due to fuel switching to natural gas and, to a lesser extent, to renewable energy sources. More than 80% of oil consumed in the EU is imported. Oil from Norway is not a source of concern since the country is part of the European Economic Area[1], but the other supplies are sometimes perceived as a potential source of insecurity for Europe’s energy supply (Checchi et al., 2008), in particular for countries like Slovakia, Poland, Hungary, Lithuania that are almost completely dependent on Russia for oil imports.
  In the short term, the continuity of oil supply is threatened mostly by geopolitical issues. In the long term, the adequacy of supply depends on the ability to keep supply and demand in balance through investments in exploration, production and refining.

  With regard to transport, the majority of crude oil imports to the EU is sea borne, which has the advantage of allowing both exporters and importers to re-direct their exports/imports, meaning that the risks related to oil transport are limited. This helps the oil market to be a true international market where the risk of scarcity is not very different from country to country. Moreover, given the wide availability of seagoing capacity, this transport chain does not represent a major concern for supply security. However, there continue to be interruptions or limitation of transit in certain critical areas from time to time, albeit generally limited in scope.

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[1] The 32 member countries of the European Economic Area include the 27 European Union Member States together with Iceland, Liechtenstein, Norway, Switzerland and Turkey.

Crude oil is not used directly, but is refined to obtain standardised products used primarily in the transport sector. The security of supply, therefore, requires the availability of suitable refining facilities to meet demand. Currently, the refining capacity in Europe is sufficient to meet demand and it seems that the present capacity is adequate also for the future even though increasingly stringent environmental regulations on products may require significant investments.

In summary, as regards oil and oil products, the security concern is very limited for transport infrastructures and transformation facilities (refineries), but is important for the availability of crude oil.

- Natural gas has its own features. Firstly, 70% of the world trade is based on pipeline transport. The pipeline physical link creates a two-way dependence, or interdependence, which is the essence of the security of supply/security of demand issue for natural gas. Secondly, given the costs of transport and geographical constraints, pipeline gas connections are regional rather than global. Thirdly, LNG trade is increasing globally and in the EU albeit with different characteristics depending on the country. For example, in 2010 LNG accounted for 19% of the total EU imports, but some countries (such as Germany, Czech Republic or Austria) were totally dependent on gas imports via pipeline, whereas others imported a significant portion of their gas as LNG (e.g. 76% Spain, 61% Portugal or 29% France). Finally, gas in many countries has become the fuel of choice for electricity generation, but in this sector it has to compete with other energy sources.

  In the case of imports of gas by pipeline, the mutual dependence between the seller and the buyer tends to limit the interest in opportunistic behaviour by the seller. However, there is always the risk that the supply is limited by lack of investment in production or by acts of sabotage (there have been many) on the transmission line. Moreover, while the seller, buyer and transit country all have an interest in a continuous flow of gas, in theory, transit countries could unilaterally stop the flow of gas.

  The LNG trade does not suffer the same problems, but the LNG market is not yet as developed as that of oil, and many contracts are effectively point to point bilateral agreements. The possible development of shale gas, especially in some countries (e.g. Poland, Bulgaria), may contribute to change the current market situation.

- In the EU, coal demand has decreased considerably since the 1980s, largely due to the switch from coal to gas-fired power generation in Western Europe and economic transition in Eastern Europe. Although dependence on imports has grown considerably, coal raises little or no concern either with regard to the adequacy or availability of transport infrastructures or the supply of the mineral at international level. Coal imports are relatively more diversified than natural gas ones in terms of the geographic origin and also in terms of the sellers. Moreover, the coal market is truly global, open and well-functioning one. At the same time, there are still considerable global proven reserves. Finally, coal is relatively safe to transport and store. On the whole, transport of coal is not a major constraint. This helps to say that dependence on the foreign supply of coal poses less risk for Europe.

- Lastly, in the case of electricity and district heating, first of all a distinction must be made concerning the energy sources used to generate these energy carriers. In the case a fossil fuel is used, the availability of the primary energy source has to be ensured. In the case a renewable energy source is used, the security of supply relates to the possibility of intermittent availability of this source for natural reasons. When the primary source is secured, then the continuity of supply depends on the reliability and adequacy of generation and transmission infrastructure. This is an internal problem that must be solved through adequate investment and good management practices. With regard to electricity, the common rule is to always have a certain reserve margin for generating capacity and to observe the *N-1 rule* for the networks. The *N-1 rule* stipulates that the continuity of supply must be ensured even if any major branch of the network were suddenly interrupted. The same is true for district heating, although the scale of the problem is local.

The external dimension of security of supply, in this case, is linked to the use of imported fuels to run boilers or power plants. Obviously this problem can be solved either by using indigenous sources (such as renewables), by securing fuel supply from abroad and by improving efficiency of energy use.

The review conducted in the previous sections has identified in a qualitative manner the risk of supply disruption associated with the use of each primary or secondary energy source. This review can be transformed into quantitative values by assigning discrete values to the stated judgments or by developing suitable tools for quantitative measurement of the factors discussed. Just to illustrate the process, in Table 1 we transformed our qualitative judgments on the potential risks into numerical values by assigning a rating, ranging from 1 (totally irrelevant for security concern) to 4 (very relevant), to each phase of the supply chain.

Table 1. Degree of potential risk of interruption associated with each phase of the supply chain

Primary source	*Transport facilities*		*Transformation facilities*	*Provision of primary source*	
	Fixed infrast. (grids, pipelines)	*Mobile infrast. (ships)*		*Physical facilities*	*Geopolitical factors*
Coal	Not applicable	1	Not applicable	2	1
Oil	1	2	Not applicable	3	4
Gas	4	2	Not applicable	3	4
Energy carrier or secondary source					
Electricity	4	Not applicable	4	See oil-gas-coal	See oil-gas-coal
Heat	4	Not applicable	4	See oil-gas-coal	See oil-gas-coal
Oil products	1	2	2	See oil security	See oil security

2.2. The probabilistic approach and its implications

The risk of supply disruption at country borders (in this section we ignore the problems to the supply continuity arising because of internal events) can be expressed in a formal way and in general terms. Assuming that the events that could lead either to an unavailability of the energy source or to the interruption of import infrastructures are independent, the probability that the energy flow supplied through any particular infrastructure “i” at any time is not disrupted can be written as:

$$P_{s,i} = P_{p,i} \cdot P_{e,i} \qquad (1)$$

where: $P_{s,i}$ = probability that the supply from the source “i” is not limited[2];

$P_{p,i}$ = probability that the “plant” or infrastructure i is in operating condition;

$P_{e,i}$ = probability that the “energy source” that feeds the infrastructure i is available.

We also denote with:

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[2] We do not consider the possibility that a plant or a source of energy is only partially available (or partially interrupted), but this limitation can easily be lifted in the following formulae.

$$\alpha_i = \frac{q_i}{Q} \tag{2}$$

the share of the imported energy through the “ith” infrastructure, where:

q_i is the quantity of imported energy through the “ith” infrastructure;

Q is the total import demand (but it could be the total consumption of that particular energy source or total energy demand depending on how we want to analyse the supply security problem).

Supposing that there are “n” independent facilities through which supplies arrive, then the probability that all of them work (P(n)) and the total supply ratio that could be delivered (α(n)) are given respectively by:

$$P(n) = \prod_{i=1}^{n} P_{s,i} \tag{3}$$

$$\alpha(n) = \sum_{i=1}^{n} \alpha_i \tag{4}$$

The expected possible supply through the existing import infrastructures is given by:

$$E_S(n) = P(n) \cdot \alpha(n) \cdot Q \tag{5}$$

Obviously, if one of the existing facilities is unable to deliver its supply (either because the transport facility or the raw material is unavailable), the total amount deliverable is lower. The probability P(n-1) that all except one facility (the “jth”) are available and the corresponding share of import demand that can still be supplied are given by:

$$P(n-1)_j = (1 - P_{s,j}) \cdot \prod_{i=1}^{n} P_{s,i} \qquad \forall i \neq j \tag{6}$$

$$\alpha(n-1)_j = (\alpha(n) - \alpha_j) = \sum_{i=1}^{n} \alpha_i \qquad \forall i \neq j \tag{7}$$

Similarly, the probability that two independent sources of supply (“j” and “k”) are simultaneously unavailable and the percentage amount of energy that could still be supplied in that case could be written:

$$P(n-2)_{j,k} = (1 - P_{s,j}) \cdot (1 - P_{s,k}) \cdot \prod_{i=1}^{n} P_{s,i} \qquad \forall i \neq j,k \tag{8}$$

$$\alpha(n-2)_{j,k} = (\alpha(n) - \alpha_j - \alpha_k) = \sum_{i=1}^{n} \alpha_i \qquad \forall i \neq j,k \tag{9}$$

By the same reasoning we can calculate the probability that any number of infrastructures is out of service at the same time and the corresponding share of energy that could be provided. It is easy to see that, if the interruption probability of each facility is low, the probability of simultaneous interruption decreases very rapidly. This explains why, as we will see, the interest of operators and of policy-makers is focused almost exclusively on n-1 situation.

The previous representation of the problem that associates a state of the system with its probability shows that, in order to promote physical security of supply, we must act on the shares of each source of supply and on the probability of interruption of each of them.

The initiatives that can be taken on supply shares in order to increase security of supply are threefold. First of all, the total amount of the shares of the sources of supply must be greater than 1(this means that we must have reserve margins for imports). The proof is immediate. If we want that, on the average, the import demand is covered by import capacity, we have to satisfy the condition that:

$$E_S(n) \geq \cdot Q \qquad (10)$$

which is satisfied if:

$$\alpha(n) \geq \cdot \frac{1}{P(n)} \qquad (11)$$

The second suggestion to increase the security of supply is that the dependence on one source (α_i) should be kept as low as possible in order to limit the maximum risk of each supply source. The proof is very simple. If we order in descending order the product of probability of interruption and the amount of energy supplied by each import line we can select the one with the greatest risk given by:

$$\text{Worst case} = \text{Max } (1 - P_{s,i}) \cdot \alpha_i \cdot Q \qquad \forall i \qquad (12)$$

If the probability of interruption is not very different from one source to another (which has to be demonstrated case by case), then the only way to limit the risk is to keep the share of each source of supply as low as possible. (QED)

From the above comes the third suggestion, namely that we must try to maximise “n”, that is the number of sources of supply (this leads to the well known suggestion that we must diversify). The proof is simple again. The best condition for limiting the maximum risk is reached when:

$$(1 - P_{s,i}) \cdot \alpha_i = (1 - P_{s,j}) \cdot \alpha_j \qquad \forall i, j \qquad (13)$$

If again we assume that the probabilities of interruption are not very different, then the best solution is when all the shares of energy supply are equal. Consequently, to limit these shares we have to increase the number of sources of supply.

The other way to increase security of supply is to act on the probability of interruption. If we consider, as we are doing, only imports, this result is difficult to obtain. The easiest way is to order the alternatives according to their a priori probability of interruption, taking into account any premia to be paid to ensure security.

2.3. Tools to limit security of supply risks

Security of energy supply is a problem to be addressed at both at individual and collective levels. Households and companies are certainly concerned with continuity of supply and can implement several measures to achieve it, but sometimes these are not enough. In case measures are not sufficient there is scope for public intervention to improve the social welfare. According to the risk analysis approach we have seen above, policymakers can handle the security problem in two complementary ways: reducing the likelihood of threats to energy security or mitigating the negative impacts stemming from limited security.

Even if we make a distinction, prevention and mitigation of risks are related to each other as their common goal is to limit the negative consequences of supply disruptions. Prevention seeks to restrict a priori probabilities and consequences, whilst mitigation attempts to limit the consequences if an adverse event occurs. For example, in order to prevent the risk of supply disruption, it is possible to promote the diversification of supply source or routes, foster the interconnection of national grids, encourage long-term contracts and stimulate internal production. Preventive policies can have also a “strategic” character. For example, investing in technological innovation and alternative fuels or in the democratisation and political stability of fuel-exporting states (Egenhofer et al., 2004). Another way is to carefully choose the suppliers and try to have mutually beneficial relationships with them.

In order to implement mitigating policies, it is possible to develop spare capacity to have reserve margins, support flexibility instruments (supply and demand flexibility, interruptible contracts, etc.), own stocks for a certain period of time. Holding stocks is a common measure to deal with supply crises, however optimising the level of stocks requires establishing the probability that an interruption of supply occurs, but also its duration.

When policymakers decide to act, they may do so either by using economic instruments, that is, with incentives or penalties, or by using instruments of command and control. A long list of market-based instruments is contained in Regulation 994/2010 of the EU on the promotion of security of gas supply (Table 2). There is a wide range of command and control measures. The most common of these is the imposition of a certain level of stocks. Another is the requirement for sellers to guarantee supply to certain consumers. We will return to these matters when we examine the policies actually followed by governments.

Table 2. List of market-based security of gas supply measures

Supply-side measures	**Demand-side measures**
- increased production flexibility, - increased import flexibility, - facilitating the integration of gas from renewable energy sources into the gas network infrastructure, - commercial gas storage - withdrawal capacity and volume of gas in storage, - LNG terminal capacity and maximal send-out capacity, - diversification of gas supplies and gas routes,	- use of interruptible contracts, - fuel switch possibilities including use of alternative back-up fuels in industrial and power generation plants, - voluntary firm load shedding, - increased efficiency, - increased use of renewable energy sources.

- reverse flows, - coordinated dispatching by transmission system operators, - use of long-term and short-term contracts, - investments in infrastructure, including bi-directional capacity, - contractual arrangements to ensure security of gas supply.	

2.4. Energy security indicators

Over the years there have been attempts to devise indicators for security of energy supply for all the major energy sources in order to identify the risk factors and quantify the exposure to volume and price risks. Various methodological approaches are currently used to capture in quantitative terms the degree of security of energy supply. Some deal with only one aspect of energy security, while others try to describe several relevant elements in one single aggregated indicator (Kruyt et al. 2009).

Within the first category, many indicators focus on a country's current diversification of energy sources or import sources as a measure of energy security. Diversity is one of the most important tools to mitigate energy insecurity and countries' vulnerability, i.e. the likelihood of domestic disruption in case of some external energy source is reduced or cut off . The most commonly used indicators for diversity are the Herfindahl-Hirschman and Shannon Indices, developed further by Stirling (1996) and more recently by Jansen et al. (2006). Other studies look at the dependence on fuel imports as indicator of energy security, as dependence is considered a measure of how much the domestic economy relies on sources of energy that are not under its control (Turton and Barreto, 2006).

On the other hand, a number of researchers have tried to develop indicators to capture the many aspects of energy security within one single indicator. For instance Jansen et al. (2004, 2007) formulated an index combing the Shannon index that captures fuel diversity and diversity of suppliers for the shares of imports of each fuel, attributing also a political stability factor to suppliers. The Asia Pacific Research Centre applies a measure that include diversity and import dependence (APERC, 2007). The IEA (2007) and Lefèvre (2007) construct two indicators for energy supply security: one deals with the physical availability and the other with price risks stemming from supply (or sellers) market concentration. Scheepers et al.(2006, 2007) propose a supply-demand index, designed on the basis of expert assessments on all possible relevant aspects of energy security, covering demand, supply, conversion and transport of energy. Gupta (2008) proposed an aggregated indicator of oil vulnerability based on seven indicators: the ratio of value of oil imports to GDP, oil consumption per unit of GDP, GDP per capita, oil share in total energy supply, ratio of domestic reserves to oil consumption, exposure to geopolitical oil supply concentration risks and market liquidity.

All indicators enable an ordinal ranking of alternative scenarios. Moreover, using a broad range of indicators, it is possible to describe the current situation and the evolution of security of supply in the EU, based on a historical series (of the indicators). However, it is important to notice that there is no ideal indicator of energy security, since its adequacy and relevance depends on the context.

Table 3. Simple and aggregated indicators of energy supply security

SIMPLE INDICATORS	AGGREGATED INDICATORS
- Diversity indices - Import dependence - Political stability - Energy prices - Mean-Variance portfolio theory - Market liquidity - Demand-side indicators - N-1 indicator - Resource Estimates - Reserve to production ratio	- Diversity-based index (Jansen) - IEA's energy security indicators - Ex-post indicator (Loshel et al.)

2.5. Private and social costs of energy supply disruptions

Supply disruption can be measured by energy not supplied, but from an economic point of view what matters is the welfare loss caused by that interruption or shortage of supply. The loss of supply can be calculated from a private or social point of view. In general, the two aspects coincide, but not if there are externalities.

The costs of supply interruptions for private consumers are usually represented by the loss they incur due to the energy not supplied. The damage costs can be assessed by different methods:

- Revealed preferences. This method involves the assessment of the financial means dedicated by a firm or individual to the prevention of supply interruption, which are indicative for the expected costs of these interruptions.
- Stated preference. This method focuses directly on explicitly expressed preferences as revealed by the willingness to pay to avoid the damage. More specifically, it is based on the contingent valuation method: consumers have to indicate in a direct way how much money they are ready to pay for more reliability, i.e. their willingness-to-pay (WTP), or how much money they want to receive in order to accept lower reliability of supply, i.e. their willingness-to-accept (WTA).
- Direct costs. Direct cost surveys request interruption costs directly from consumers. Firstly, consumers are requested to identify the different costs categories in case of an interruption. For industrial and commercial consumers these may be lost sales or production, spoilage, damage, etc. The second step is to attach an economic value to each cost category. Interruption costs are then obtained by summing up all the individual costs.
- Case studies. Interruption cost case studies involve the gathering of a wide variety of data and facts immediately after the occurrence of a large-scale electricity or gas disturbance.

As mentioned, social costs may not coincide with the sum of private costs. It can also be easier to calculate directly the total costs rather than aggregate costs for individual consumers and then summing them to calculate social costs. Nevertheless, assessing the costs of supply disruptions for the society poses difficult methodological and empirical issues.

The magnitude of the social costs of an energy disruption are profoundly affected by several factors. The two main determinants are the duration, as an interruption prolongs interruption costs increase, and the size of the disruption. The structural characteristics of the economy also play a crucial role: the flexibility of energy sector, i.e. its capacity to shift from one source to another, the energy intensity of the economy, its self sufficiency in a given source production as well as the level of dependence on the import of a given energy source.

A final caveat is worth mentioning about the value of lost security of supply. Both individuals and society are generally *risk averse*. Consequently the simple calculation of the costs resulting from energy supply interruption leads to an underestimation of the WTP of individuals and society. Although the level of risk aversion is difficult to evaluate, at the social level we can expect that the attitude towards risk basically depends on the country's import dependence. The higher the energy dependence, the greater the country's vulnerability to energy supply disruption and the higher the risk aversion to accept supply disruption of energy imports.

3. The pricing component of energy security

Reference to affordability in the definition of energy security is aimed at drawing attention to the possible adverse impacts of sudden large price increases, given that commodity prices affect economic growth, social wealth and industrial competitiveness. Price variations can be due to supply/demand actual or anticipated imbalances, but they can also result from speculative movements and market power abuse. It is important to note that gradual long-term energy price increases could be absorbed by the market with limited consequences on society – by adjusting supply to meet demand, adapting infrastructure to deliver this supply to markets, promoting investments and contracting or improving technology and availability of primary energy sources. Nonetheless, sudden unexpected and pronounced price hikes may cause serious concern, creating monetary and trade imbalances between energy producing and consuming countries especially harming the economy of the latter (Bigano et al., 2009). Consequently, a long-term trend of rising prices for energy imports has a different implication for an economy than a sudden price hike or price volatility.

To address the issue of energy security in terms of affordability, it is essential firstly to identify the likelihood of the occurrence of energy price shocks and evaluate their possible consequences to the economy.

3.1. Price volatility and price shock

Energy markets are characterised by extremely high levels of risk, usually expressed in terms of price volatility. More precisely, the risk associated with the change in prices is best expressed through the volatility of their returns (i.e. the percentage change in price in a unit of time[3]).

Time series plot of monthly Brent crude spot prices and natural gas import prices over the 1992-2010 period (in constant 2010 USD), shown in Figure 1, reveals a random walk behaviour: future values of energy price are unrelated to the past values; or, in other words, oil and gas prices follow no predictable path.

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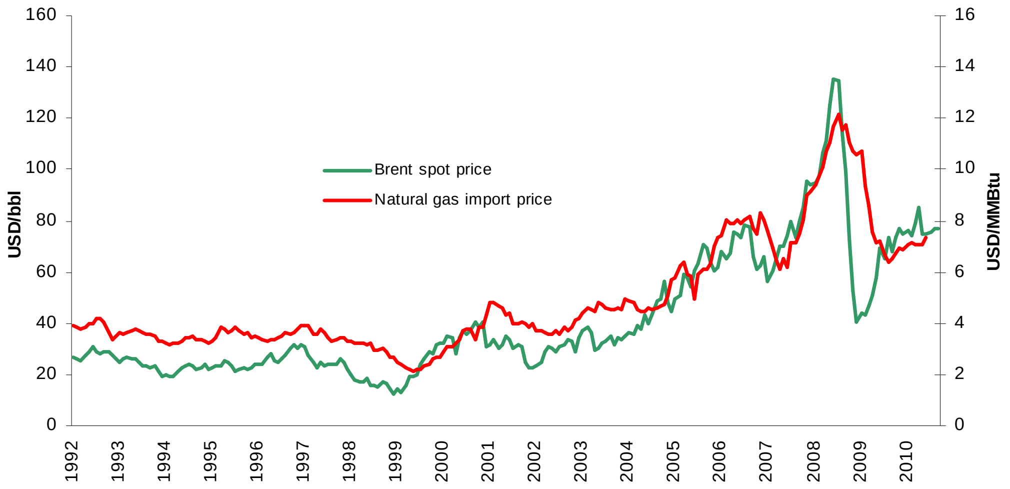
[3] If P_t is the price of the commodity on a given month, the percent return R_t is defined as: $R_t = \frac{P_t - P_{t-1}}{P_{t-1}}$

Due to this characteristic, it can be easily shown that price returns are normally distributed[4]. A normal distribution is the most commonly observed distribution and is typical in many natural process characterised by random variation. The shape of a normal distribution resembles that of a bell, completely described by two parameters: mean and variance (or standard deviation, that is the square root of the variance). When the mean and variance are known, then one essentially knows as much as if one had access to every point in the data set. In the case of oil and natural gas prices' return, the mean is (approximately) zero, and negative and positive returns are equally likely to be observed.

Figure 1. Monthly Brent spot market price and Natural gas import price in constant 2010 money



Source: IEA

What matters is to provide an adequate measure of the volatility. There are several mathematical models to estimate price volatility, characterised by different complexity and computational costs: the historical volatility, the Autoregressive Conditional Heteroskedasticity (ARCH) model, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, the Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model, the conditional distribution, the implied volatility. The simplest model to estimate of volatility is based on the historical volatility: the volatility at time t is given by the standard deviation of the series calculated over the last N months. This historical volatility, that can be more precisely termed as an N-month simple moving average volatility, assumes that volatility is constant over the estimation period and the forecast period.

Such model applied over a 20 years series to calculate the yearly price return historical volatility, computed as $\sigma = \sigma_t\sqrt{t} = \sigma_t\sqrt{12}$ where σ_t is the monthly historical volatility, gives:

$\sigma_{OIL} = 0.34$ for crude oil;

$\sigma_{GAS} = 0.20$ for natural gas.

However, as gas increasingly becomes traded on markets, its volatility would be expected to grow (possibly above oil's).

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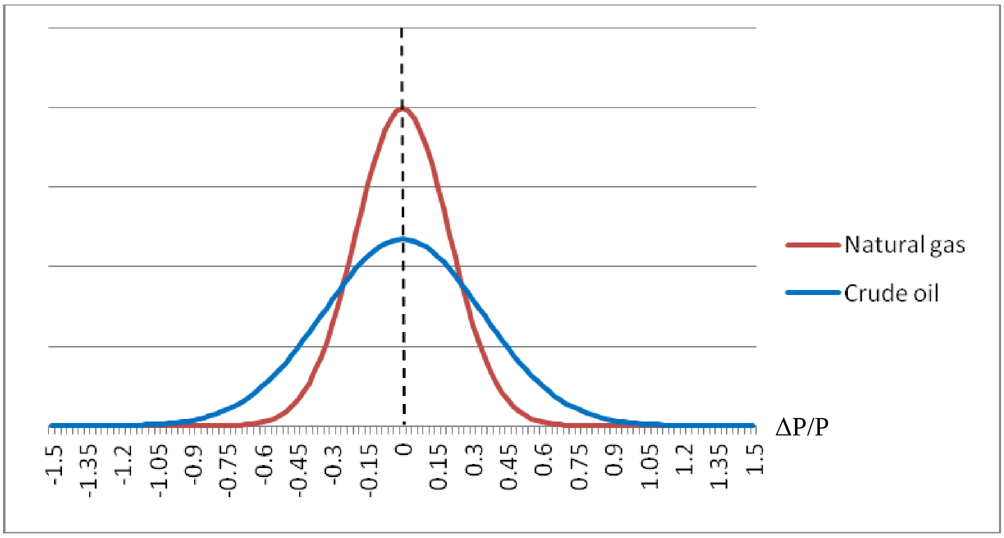
[4] The assumption of normally distributed returns implies a lognormal price distribution, which guarantees that prices will never be negative.

According to the empirical rule, for a normal distribution a) 68% of the data will fall within 1 standard deviation of the mean; b) 95% of the data will fall within 2 standard deviations of the mean; and c) almost all (99,7%) of the data will fall within 3 standard deviations of the mean. For example, given a mean equal to zero, in the case of natural gas 68% of the data will fall within –0.2 and +0.2; 95% of the data within – 0.4 and +0.4 and, finally, 99.7% of the data within -0,6 and +0,6.

Figure 2. Probability density functions for yearly oil and gas price returns



However, it should be noted that individuals do not appear to be strongly concerned with overall volatility: rather they seek to avoid upside risk, while retaining downside risk (Cita et al., 2007). As a result, it appears that their aversion to risk may be asymmetric. For this reason, great focus will be given on the right side of the bell curve, i.e. on positive price increases, in order to evaluate the welfare loss due to increase in price rather than the welfare benefits due to price decline.

It is very difficult to establish reliably the likelihood of future energy price shocks. However, in literature there are at least three approaches to cope with this uncertainty:

- Analyse the historical pattern and frequency of events. This approach is founded on the expectation that the past is a reasonable indicator of the future.
- Apply expert judgement. This approach yields “subjective” probabilities, but goes beyond the historical data to consider what might have happened, under changing conditions in the future (e.g. Delphi method).
- Explicitly model and analyse the source of prospective price shocks. It entails such methods as numerical modelling of OPEC power (for oil), estimates of political and economic incentives for suppliers to behave cooperatively or opportunistically, and the stability of the cartel supply (Leiby et al., 2000).

Of these three approaches, the majority of the academic papers rely on the historical evidence to assign a probability to large but unlikely price spikes. In this case the difficult task is to establish the point at which a price increase becomes critical. This aspect will be examined more in detail in Paragraph 5.2.

3.2. Economic loss due to energy price increases

Pronounced and unforeseen energy price increases can have damaging effects on the economy. Several studies have analysed the inverse relationship between higher energy prices and reduced economic growth rates. Among them, Brown et al. (2002) point out the energy price impact on economic activity through four transmission channels.

The classic supply-side effect explanation mentions the rising price of a key production factor as the trigger. Increasing costs of production results in a lower growth of output and, hence, of productivity. Consequently, the growth of real wages declines and consumers reduce their savings or increase their debt as to smooth out their consumption. As a result, real interest rates rise and boost inflation if the supply of money is not adapted to the change in money demand. If nominal wages are sticky downward, unemployment will grow reducing production further.

A different explanation is given by the ‘income transfer’ approach, according to which an increase in energy price deteriorates terms of trade for energy importing countries. This approach stresses the fact that rising energy prices transfer income from energy-importing countries to energy-exporting countries, leading to a fall of the purchasing power of firms and households in energy importing countries. As the latter have a lower propensity to consume, aggregate spending and, hence, aggregate production decline.

The other approaches focus on the role of the supply of money. The ‘real balance effect’ explanation states that a rising energy price would lead to an increase in money demand, while money supply grows insufficiently as to meet the higher demand. Consequently, interest rates rise and economic growth decreases.

The final approach sees ‘the failure of monetary policy’ as the major explanation. According to this approach, inadequate policies of monetary authorities were the major cause for economic deterioration after an oil price shock. Recessions in energy importing countries are less the direct result of higher prices and more the consequence of economic policies adopted to alleviate the price shock.

With regard to *importing countries*, supply-side shocks result from variations of imported raw material costs, with external effects and internal effects. The main external effect of an increase in energy prices is the income reallocation between importing and exporting countries. For an importing country, a price shock directly reduces GDP, because the increased expenditure for imported energy reduces the income available for other goods and services. Extensive literature consider changes in GDP a measure of how changes in energy prices affect the economy and the social welfare in net importing countries (for example, Constantini et al., 2004; Hedenus et al., 2007; Markandya et al., 2004). The quantitative strength of the relation between energy price and economic activity is summarised in the so-called energy price elasticity of GDP: the percentage change in GDP due to a one-percentage change in the energy price.

On the other hand, the internal effects of a price shock are linked to the typical economic variables. Looking at the past, after the main oil crises, countries were stricken by higher inflation, higher unemployment, lower exchange rates, trade and payment imbalances, weak business and consumer confidence (Constantini et al., 2004).

In summary, for countries that import energy sources, an increasing energy price in the global market can be seen to have three main effects on their economies:

- A direct effect on the economic activity because more spending will be allocated to energy costs;
- A financial effect because of the rise of inflation and interest rates; and
- A trade effect relating to an increased energy import bill, which worsens the trade balance.

The magnitude of the economic costs of an energy price increase is deeply affected by the level of a country's vulnerability. It can be represented by the ratio of energy imports to GDP, which, in turn, may be broken down into three complementary indicators. For the case of natural gas, for instance, we obtain:

$$\text{Natural gas vulnerability} = \frac{\text{Net Gas Imports}}{\text{GDP}} = \frac{\text{Net Gas Imports}}{\text{Total Gas Use}} * \frac{\text{Total Gas Use}}{\text{Total Energy Use}} * \frac{\text{Total Energy Use}}{\text{GDP}}$$

Where: the ratio $\frac{\text{Net Gas Imports}}{\text{Total Gas Use}}$ measures the self sufficiency in natural gas production; it can be improved by domestic exploration, discovery, production, management of demand. The second ratio $\frac{\text{Total Gas Use}}{\text{Total Energy Use}}$ measures the dependence on natural gas as energy source; it can be affected by policies to encourages inter-fuel substitution or diversification of the energy portfolio. Finally, the ratio $\frac{\text{Total Energy Use}}{\text{GDP}}$ measures the energy intensity; it can be improved by energy efficiency measures and also by a shift in the pattern of production from energy intensive activities to less energy intensity sectors (Chevalier, 2006).

3.3. Tools to mitigate pricing security risks

A wide range of policy options directed at security of supply, in terms of affordability, exists. For example, the instrument of strategic stocks seems to be an adequate measure to cope with price shocks: energy released from strategic stocks could compensate for the price effect of a shock (de Joode et al., 2004). The benefits of stockholding are measured by avoided costs of damage to the economy. They consist of two components: avoided loss of GDP as the oil price rises less than would have been the case without the release of oil, and avoided loss of import expenditures due to the lower price of energy.

While strategic stocks measures could only be useful in dealing with short-lived market disturbances, fuel substitution makes sense also to cope with long-lasting crisis, occurring for example as a result of effective cartel behaviour of energy-producing countries. Also in this case, there are two types of direct benefits: firstly, the cost increase coming from the energy price surge is partly avoided; secondly, welfare effects follow from the reduced increase in prices.

A more practical hedge programme is designed to offer an insurance-type coverage bought in the financial market, which provides protection against price spikes. A common (and easy to price) insurance tool is represented by call options: by purchasing a call option we have the right to buy a given quantity of energy on a certain date (the maturity date) at a pre-determined price (the strike price), paying the so-called option-premium. Guaranteeing that consumers will not pay more than the strike price, this hedge strategy can be described as "price cap" strategy. Whether the call option will be exercised or not depends on what the strike price will be with respect to the market price at the option's maturity date. The call option will be exercised – i.e. consumers can buy energy at the strike price avoiding the higher market price – only if the strike price is lower than the market price. In any case, consumers would have to pay a premium to own the option.

4. Policies ensuring energy supply

4.1. Security of energy supply as a public good: the issue of externalities

In light of the above discussion, the lack of energy security can generate costs due to either a disruption of supply (partial or total) or a sharp and abrupt price increase. There is general agreement within the international literature about the nature of these costs, affirming that disruption in supply and dramatic price increase might have impact on the wellbeing of individuals. These costs are not fully internalised by consumers and investors in their decisions and ignored by markets in the determination of prices. Because most of the economy-wide costs due to the lack of energy security are "external" to the cost-benefit consideration of private agents, in the sense that they are not completely borne by the fuel user, they become a concern for economic policy, but affect others in the economy as well. This kind of costs is classified under the category of economic externalities, as they refer to the spill-over effects of one person's activities on another person's welfare. The concept of externality, well known for its application in the environmental arena, can, therefore, be also applied to the security of energy supply.

In a perfectly competitive market (that is, when every stakeholder has complete information about potential risks and the respective costs of reducing them, consumers are able to express their willingness to pay for additional security, and there are no market failures) market mechanisms would lead to an optimal level of security, as market participants internalise the risk of disturbances in supply and demand and prices generally incorporate consumers' willingness to pay for different levels of exposure to risk. However, energy security by definition possesses public good characteristics and relates to problems of market failures.

The first reason why the market may fail in providing energy security is the *absence of complete and adequate information* about the potential risks of lack of energy security and the respective costs of reducing them, so that economic agents cannot correctly assess the size, risks, and social impacts of energy disruption or price increase and fully internalize them. However, even if agents had accurate information about energy market risks, market failure might exist for another fundamental reason: agents may be able to internalize any cost of energy use that they expect to bear, but they will typically ignore any external costs that their decisions impose on other consumers (Brown and Huntington, 2010). In this case the market failure results from the presence of *negative externalities*.

Moreover, energy market may fail because of *imperfect competition*, arising from concentration of market power. Monopolies or cartels lead to an output below the quantity at which the marginal social benefit is equal to the marginal social cost.

Finally, energy security shows features similar to those of public goods, namely it is a non-rival good and non-excludible in consumption. The tricky issues about public goods lie in the fact that their provision creates incentives for a free rider behaviour: consumers can take advantage of security of supply without contributing sufficiently to its availability, i.e. without paying for it or paying less than its full cost.

Because of these market failures, the objective of individuals may deviate from the objective of society as a whole, so that the government intervention is justified. Without such intervention, it may be argued that market imperfections would lead to an under-provision of security. Although there are different market failures, negative externalities are of particular relevance for the security of energy supply (Mulder et al., 2007). As economists suggest, when externalities are present, markets are not efficient as long as these external costs are not internalized and economic agents do not take them into account. In principle, the means to avoid an externality is to ensure that it is included in the price paid for the good that caused it. This requires identifying and quantifying security of supply externalities arising from lack of energy security and providing a tool to internalise them. Specifically, when performing an economic appraisal of energy projects, the economic analysis should include any social costs not considered by the financial analysis (as they do not generate actual cash flows) to compensate any impacts that spill over from projects towards economy, by applying a monetary "penalty" for security on the energy price.

It is important to note that liberalisation can be expected to benefit security of supply. Energy market liberalisation have affected governments' ability to react to security of supply challenges, as it enhances security of supply by increasing the number of market participants and improving flexibility of the energy systems. Moreover, markets can ensure that some of the costs of security of supply are included in prices, though these components may not be immediately transparent which in turn can lead to a situation in which consumers are prepared to pay a premium for increased security of supply or to accept a reduced level of security in exchange for lower prices (Nyquist et al, 2001).

4.2. Defining the optimal level of security of supply from a social point of view

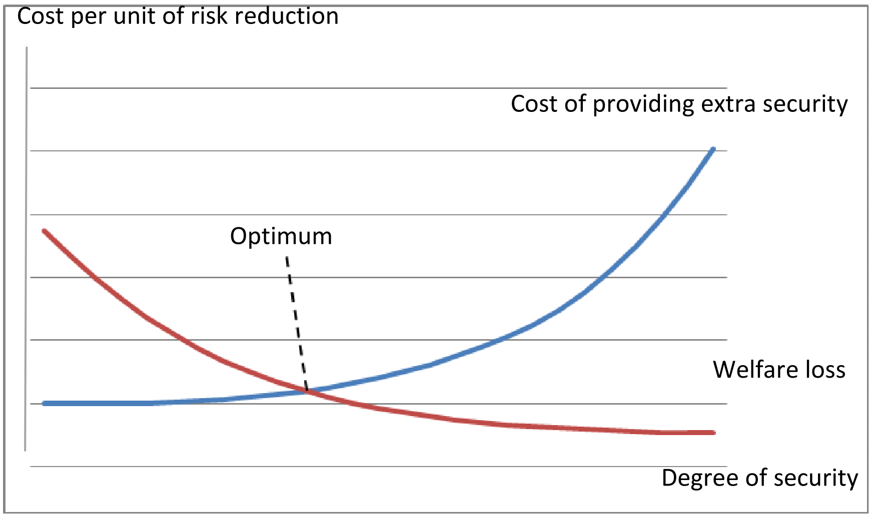
Addressing the issue of security of energy supply as a problem of negative externalities requires policymakers' interventions to correct the market failure and guide economic agents' decisions. Policymakers should provide policies to improve energy security and, above all, they should define and set a quantitative target for security of energy supply (any standard such as a level of storage, margin reserve, N-1 criteria, etc.) to be achieved. However, EU reliability standards are still based on rules-of-thumb, instead of calculated optimal economic level of security of supply. From an economic perspective, the optimal level of security of energy supply equates the marginal potential welfare losses, resulting from the damage due to either a disruption of supply or a price increase, and the marginal costs borne by the society to limit these losses. This means that to evaluate whether any given level of security is optimal or even adequate it is necessary to trade off benefits from extra security against the costs of providing it. Accordingly, achieving a very high probability of continuity of supply or a relatively steady price might not lead to the best solution for society. It would minimise the potential loss arising from lack of security, but the costs could be higher than the avoided losses.

By applying the standard theory we can say that the optimal level of security of supply is reached when the *marginal cost ensuring security of supply* equals the *expected damages of supply disruption*, as shown in Figure 3.

This requires the public authorities to know on the one hand the expected damage caused by each event (that is the probability times the consequences of that event) and on the other hand the cost to reduce the expected damage of that event (i.e. the cost to reduce the likelihood of the event and/or to mitigate its negative consequences).

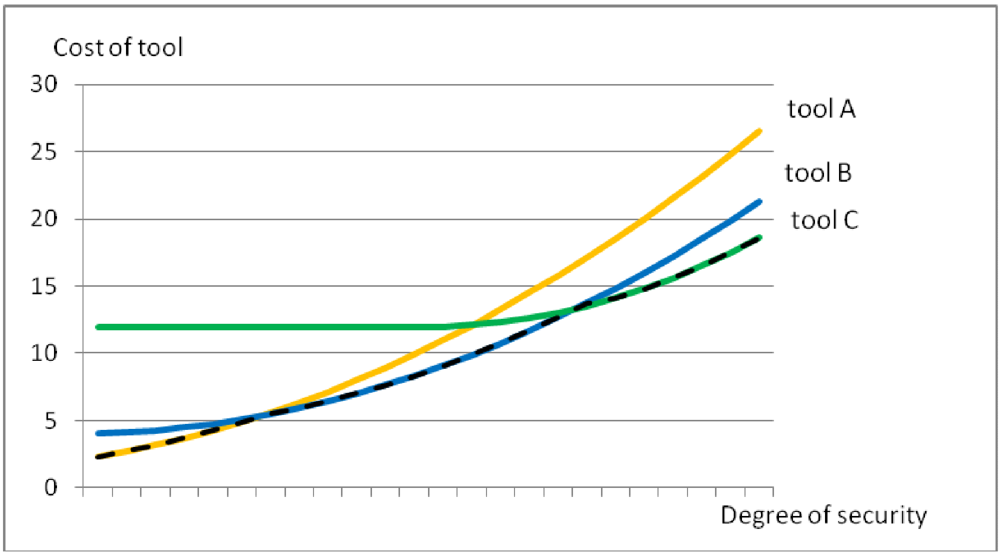
One can easily understand that it is difficult to obtain such detailed information, due to the difficulty to measure the quantitative features of supply disruption and price shock events (probability, timing, duration, etc.). Consequently, a less difficult task is to check that the necessary condition is verified, i.e. the total costs devoted to security of supply have to be lower than the total expected damages without public intervention.

Figure 3. The optimal level of security



Even in this simpler form, a good policy needs to compare costs of different measures to foster energy security of supply. Each solution implies different costs, fixed and variable, which may vary depending on the level of security to be guaranteed and on the characteristics of the economic system under consideration. However, no instrument is characterised by a cost curve at any point below the other instruments’ cost curves, in other words there is no tool always preferred to others from an economic perspective, as shown by way of example in Figure 4. This requires the selection of the least cost solution for any degree of security of energy supply to be guaranteed. It implies that the curve of the possible solution corresponds to the envelope of the minimum cost curves (the broken line in the figure).

Figure 4. Costs of different tools to foster energy security of supply



In order to determine an adequate level of security of supply, we assume also that individuals and society show risk averse behaviour. In other words, they do not value the consequences of lack of security of supply at the correct cost, but perceive risks to be greater than they really are, so that they are willing to pay increasingly more as the negative impact becomes more serious.

The following section shows how policymakers have acted in practice.

4.3. Review of EU energy security policies for different energy sources

The importance of energy security of supply is evidenced by the debate launched by the European Commission, which shows that ensuring security of energy supply represents a recurrent and explicit objective in EU energy policy. It needs, at the same time, to be consistent with the other goals of the EU, namely economic efficiency and environmental protection. A feature of the development of EU energy policy is that the relative importance of these three main objectives has varied over time, depending on economic, political and historical factors.

The treatment of energy security of supply in European policy is usually a requirement defined in qualitative rather than operational terms, thus failing to address the issue in a rigorous way to support policy decisions.

The political problem is to choose the desired level of energy supply security and the means to achieve it. The general preference in the EU is to use tools that encourage market response, that is more flexibility (see table 2), but sometimes it is necessary to rely on standards. Standards can be applied to transport or supply facilities or to energy sources. The N-1 criterion is an example of a standard applied to infrastructure; with regard to energy sources, the most commonly used standard is the requirement to maintain a certain level of stocks.

The policy maker must not only identify the standard to apply, but also its level, that is justified according to at least the necessary condition recalled above (i.e. the total costs devoted to security of supply have to be lower than the total expected damages without public intervention). For example, in the case of storage, the duration of stock coverage for various types of consumers must be decided.

With Regulation 994/2010, the EU aims at safeguarding the security of gas supply by ensuring both prevention of and a coordinated response to a supply disruption and by securing the proper and continuous functioning of the internal gas market. The Regulation introduces two standards at EU level: an *infrastructure standard*, according to which Member States shall ensure that, in the event of disruption of a country's single largest gas infrastructure, the capacity of the remaining infrastructure, determined according to the N-1 formula, is able to satisfy total gas demand; and a *supply standard* to secure supply to protected customers (i.e. households, small and medium-sized enterprises, essential social services) under severe conditions: in the event of a seven day temperature peak and for at least 30 days of high demand, as well as in the case of an infrastructure disruption under normal winter conditions.

As regards oil and oil products supply, compulsory stocks are used as the primary tool to ensure security of supply, since the concern is limited to the availability of crude oil or refined products, and, as we have already seen, it does not apply to the transport infrastructure. Through the Directive 2009/119/EC, the EU has revised the oil stockholding system, bringing it into line with the existing rules of the International Energy Agency. Repealing the preceding decisions, it stipulates that Member States must maintain a total level of oil stocks corresponding at least to 90 days of average daily net imports or 61 days of average daily inland consumption, whichever of the two is greater. Moreover, Member States are invited to hold compulsory stocks of specific products corresponding to at least 30 days of consumption.

Although there is no economic assessment proving that 90 days of average imports is the optimal level of stocks (it could be higher or lower), we may assume that the security of supply external cost is fully internalised by the current standard.

Coal supply, as discussed above, raises no concern either with regard to transport infrastructure or to the availability of the mineral at international level. Not surprisingly, neither the EU as a whole nor single Member States have introduced requirements for security of supply of this energy source. In other words, if we accept that policymakers correctly evaluate the supply situation, we can conclude that as a first approximation that there is no physical security of supply externality attached to the coal consumption.

Moreover, the EU establishes obligations aimed at safeguarding security of electricity supply and ensuring the proper functioning of the EU internal market for electricity, an adequate level of interconnection between Member States, an adequate level of generation capacity and balance between supply and demand (Directive 2005/89/EC). The aim, in the short term, is to ensure the continuity of electricity supply by maintaining an appropriate level of operational network security and of generation reserve capacity and, in the long term, to facilitate a stable investment climate for generation, transmission and distribution capacities in case no specific electricity standards (e.g. N-1 principle, reserve margin, minimum stockholding obligations, etc.) are set. Although security of supply of energy carriers (mainly electricity) is important for the welfare of society, it represents an internal problem whose costs are internalised in the price of product or service.

5. A methodology to quantify the security of energy supply externalities

The ultimate objective of this paper is to provide a methodology to evaluate security of energy supply externalities as part of the economic analysis of energy projects. Such analysis involves the appraisal of the project contribution to the economic welfare of a region or country, assessing whether the project improves, worsens, or does not affect the initial level of security of supply. For energy project appraisals, the systematic integration of such externalities in cost/benefit analysis is expected to support a more comprehensive and accurate ranking of projects and project alternatives.

Quantifying the external costs of security of energy supply would assist public and private investment decisions, internalising the implication of the lack of energy security and helping to rank investment priorities in more accurate and efficient manner.

In line with the definition of energy security (Chapter 1), we employ a methodology which evaluates the two constituent components of the issue – the physical component and the price component – separately, thus:

External cost = Physical availability component + Price increase component

In the analysis, we only focus on the supply of natural gas as a representative case, as gas imports through pipelines is the most critical dependence compared to the import of other fossil fuels and, furthermore, the corresponding externalities are not fully internalised.

As shown in the following paragraphs, the basic idea of the methodology to assess the costs of security of supply is to quantify the costs of any initiative that can counteract the damage to the welfare of the society caused by a lack of security of supply.

5.1. Assessing the physical availability component of energy security

After the Ukraine-Russia gas dispute that stopped most of the Russian gas supplies to Europe in January 2009, the Commission undertook a review of Directive 2004/67/EC approved a few years before considering it not sufficient to guarantee the security of gas supplies. The analysis led to the following conclusion. “In the changing gas market, supply and transit disruptions must be expected. Despite much effort in developing international cooperation and partnership, there are continuing questions about matching supply side investments and demand, and political dimensions of supply and transit risks” (SEC(2009) 979). To address these issues, Regulation No 994/2010 establishes, among other matters, two types of standards: one relating to infrastructure, and one to supply.

5.1.1. Infrastructure standard and N-1 criterion

The European infrastructure standard stipulates that:

“In the event of a disruption of the single largest gas infrastructure, the capacity of the remaining infrastructure determined according to the *N-1 formula* […] is able to satisfy total gas demand in the calculated area during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years” (art.6, par. 1 of Regulation (EU) 994/2010).

The general formula of the standard to be used, taking into consideration also the possibility of demand-side measures (art. 6, par. 2), is the following:

$$\alpha(N-1) = \frac{EP_m + P_m + S_m + LNG_m - I_m}{D_{max} - D_{eff}} \geq 1$$

where:

EP_m	is the total daily capacity to deliver imported gas at the border entry points
P_m	is the total daily production capability that can be delivered at the internal entry points
S_m	is the total daily withdrawal capacity from internal gas storage
LNG_m	is the total LNG daily capacity to send-out gas at the internal entry points
I_m	is the daily capacity to supply gas from the single largest gas infrastructure. When several gas infrastructures are connected to a common upstream or downstream gas infrastructure and cannot be separately operated, they shall be considered as one single gas infrastructure.
D_{max}	is the daily maximum demand occurring during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years
D_{eff}	is the daily demand that can be covered with market-based demand-side measures.

The willingness to pay to avoid gas supply disruption can be calculated from the costs to meet this standard. The implicit assumption is that society pursues security of supply until it is economically viable. In other words, we assume that use of control costs to value externalities implies that legislators are able to make optimal decisions when imposing policy instruments to achieve such outcome.

In summary, indications about the value that the society gives to energy supply disruptions can be computed by assessing what it costs society to guarantee that the N-1 principle is always complied with. This reasoning can be applied in the appraisal of projects too. When a new project (especially the import of gas) is proposed, we must firstly investigate its impact on the compliance with the N-1standard. Three cases may be contemplated:

- If the standard is satisfied and remains so even with the new project, then the project does not engender either costs or benefits in terms of security of supply, therefore we can conclude that this cost has already been internalised.
- If the standard is met without implementing the new project, but not with its implementation, then the project has a cost in terms of security of supply. The least cost solution must be identified and that cost of meeting the N-1 standard should be added to the project under appraisal.
- If the rule is satisfied only when a new project is implemented, then the project involves a benefit in terms of security of supply, indicating positive externalities

In order to assess the cost (or benefit) of a project from the security point of view, it is possible to resort to the levelised cost (LC) approach to calculate the value to add (subtract) to the price of gas. More specifically, the LC can be obtained by dividing the present value of the total cost (or the avoided cost, in case of benefits) of building and operating the least cost backup solution to meet the N-1 rule over its economic life by the present value of total energy supplied by the project under examination:

$$\mathrm{LC} = \frac{\sum_{t=1}^{n} C_t \cdot (1+r)^{-t}}{\sum_{t=1}^{n} E_t \cdot (1+r)^{-t}} = \frac{\textit{total discounted costs to comply with the standard}}{\textit{total discounted energy supplied by the project}}$$

where:

C_t = cost of the backup solution in the year t

E_t = supplied energy in the year t

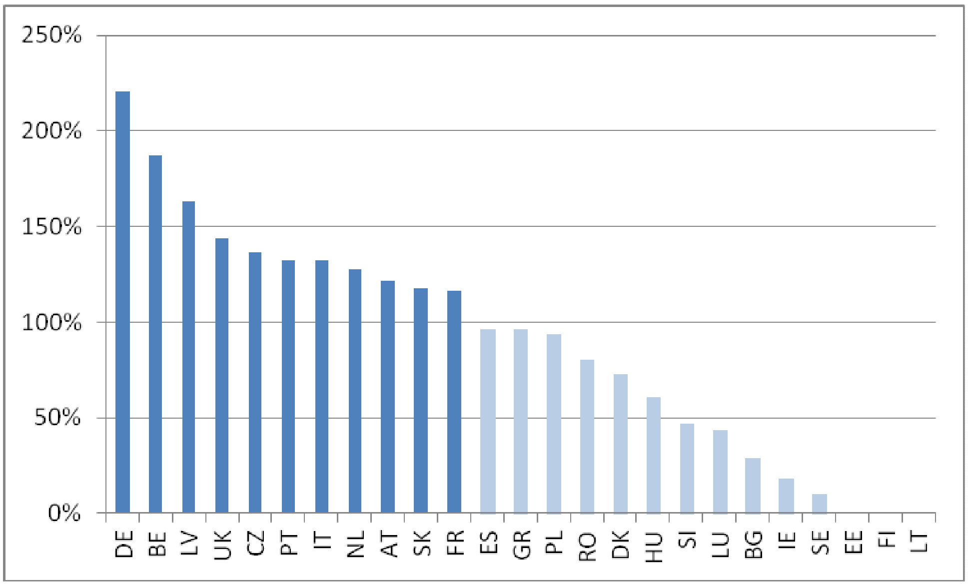
r = discount rate

n = life of the system

Table 4. Preliminary calculation of N-1 for Member States is provided by the European Commission's Impact Assessment (SEC(2009) 979 final) and the authors' estimates.

Mcm/day	Production withdrawal capacity	Maximal Consumption	Storage Withdrawal capacity	LNG send-out capacity	Incoming Pipeline capacity	Single largest infrastr.	Single largest supplier.	α(N-1) supplier
Austria	12.16	49.41	48.00	0.00	208.31	162.13	208.31	122%
Belgium	0.00	139.20	22.80	45.87	322.36	95.79	130.87	187%
Bulgaria	0.30	15.60	4.20	0.00	78.03	78.03	78.03	29%
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Czech Republic	0.30	67.60	55.01	0.00	159.67	122.58	122.58	137%
Germany	45.00	400.00	463.32	0.00	536.23	103.98	161.25	221%
Denmark	29.90	25.70	18.80	0.00	0.00	29.90	29.90	73%
Estonia	0.00	4.30	0.00	0.00	7.54	7.54	7.54	0%
Spain	0.00	231.21	10.54	185.63	79.25	52.62	52.62	96%
Finland	0.00	1.00	0.00	0.00	21.75	21.75	21.75	0%
France	2.40	370.00	231.00	75.40	199.63	59.94	79.27	116%
Greece	0.00	14.00	0.00	13.46	13.44	13.46	13.44	96%
Hungary	9.00	92.50	47.50	0.00	69.92	57.51	69.92	61%
Ireland	1.00	20.30	2.60	0.00	31.06	31.06	31.06	18%
Italy	24.00	425.00	295.85	42.30	310.22	109.77	109.77	132%
Lithuania	0.00	16.00	0.00	0.00	29.32	27.16	29.32	0%
Luxembourg	0.00	5.98	0.00	0.00	7.43	4.85	4.85	43%
Latvia	0.00	9.00	14.69	0.00	21.40	16.01	21.40	163%
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Netherlands	440.00	235.00	153.02	0.00	147.19	300.00	440.00	128%
Poland	6.48	71.20	34.20	0.00	158.67	99.21	132.74	94%
Portugal	0.00	19.30	7.00	18.56	16.82	18.56	16.82	132%
Romania	34.30	75.00	25.80	0.00	40.33	24.17	40.33	80%
Sweden	0.00	6.00	0.60	0.00	10.25	10.25	10.25	10%
Slovenia	0.00	5.80	0.00	0.00	9.94	7.24	7.24	47%
Slovakia	0.30	29.90	34.87	0.00	339.38	301.20	339.38	118%
UK	231.00	544.17	126.57	171.81	331.28	91.84	77.86	144%

Figure 5. Preliminary calculation of α(N-1) for Member States, based on loss of supply from the single largest supplier



According to these preliminary calculations, fourteen Member States do not meet the N-1 standard. These countries are in a variety of situations and could bring a variety of security of supply measure to bear.

Sweden, Finland, Denmark, Lithuania and Ireland are relatively independent of external gas connections. In any case, Sweden relies very little on gas on its energy mix, and Finland's gas users, mainly industry, have made substantial fuel switching provisions. In order to meet the standard Denmark, Lithuania, Ireland and Poland are focusing on the construction of new interconnectors and other infrastructures.

In addition to the introduction of the N-1 rule, the EU regulation contains the obligation that each cross-border interconnection between Member States must be capable of operating in both directions. This bi-directional capacity of transport standard has been introduced for security reasons. However its cost is limited compared to that of N-1 principle.

5.1.2. The supply standard

A supply disruption may also occur when existing facilities are fully available but their capacity is not large enough to meet demand. As regards this risk, the Regulation makes a distinction between protected and unprotected customers. Protected customers are household customers connected to a distribution grid and, if a Member State so wishes, small and medium-sized enterprises and district heating installations. All other customers are not protected by law against supply interruption and must look for coverage of this risk autonomously. This is in line with the general principle adopted in the EU that the market is the best solution to face the problems.

For protected customers the supply standard states that the "gas undertaking", as identified by the regulatory authority, must ensure the continuity of supply even "in the following cases:

a) extreme temperatures during a 7-day peak period occurring with a statistical probability of once in 20 years;

b) any period of at least 30 days of exceptionally high gas demand, occurring with a statistical probability of once in 20 years; and

c) for a period of at least 30 days in case of the disruption of the single largest gas infrastructure under average winter conditions" (art. 8, par. 1).

Obviously the supply standard has a cost too. Normally this cost should be added to other costs of supply and it corresponds to the internalisation of the cost of security of supply. To calculate this cost, we have to know what tools are available and what are considered adequate to meet the standard (just physical storage or other contractual arrangements).

5.2. Price component

Addressing the "price risk" requires three different conceptual steps: first, assessing the loss incurred by society because of an energy price shock; second, evaluating the willingness to pay of a risk averse society in order to limit the potential damage and last, identifying the least-cost tool to restrict the losses and assessing its costs.

5.2.1. Welfare loss

We define the economic losses experienced by society, as a result of energy price increase, in terms of society's loss of well-being. More specifically, we consider changes in GDP as an approximation of changes in the social welfare in net import countries[5].

In order to estimate the direct negative effect resulting from energy price shocks, we use the "simple net import model" developed by the World Bank.[6] The basic idea is that rising energy prices imply an additional wealth transfer from importing countries to exporting countries, resulting in a reduction in GDP. Although we assume that the entire value of the higher prices is reflected in a reduction in GDP, we recognize that the energy price elasticity of demand is not zero, even if in the short run it tends to be very low in many countries. As a consequence, the GDP decline due to price increase is mitigated by the effect of energy price elasticity of demand: as prices go up, producers and consumers substitute away from energy or between energy products, reducing energy demand, lowering the value of net imports, thus offsetting the decline in GDP. We can estimate the direct impact of import energy price increase on GDP using the following formula:

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[5] As seen before, limiting the analysis to the GDP response leads to a rough value of the overall economic damage arising from a price shock, as the assessment of the impact of energy price shocks on the economy is actually much more complex.

[6] UNDP/ESMAP (World Bank) "The Impact of Higher Oil Prices on Low Income Countries and on the Poor", March 2005

$$\% \frac{\Delta \mathrm{GDP}}{GDP} = \% \frac{\Delta \mathrm{P}}{P} * (1-\varepsilon) * \left(\frac{NI}{GDP} \right)$$

where:

- $\% \frac{\Delta \mathrm{GDP}}{GDP}$ is the percentage change in GDP;
- $\% \frac{\Delta \mathrm{P}}{P} = \frac{P_{t+1} - P_t}{P_t}$ is the percentage change in price of imported energy;
- ε is the price elasticity of demand (in absolute value);
- NI is the net import of energy (in monetary terms)

According to the model, the magnitude of the direct effect of a given energy price increase on GDP may vary depending both on the extent of the price change (i.e. the level and the duration of the price increase) and the characteristics of the economy: the loss caused by energy price increases is a function of the weight of imported energy costs in the national income, the degree of dependence on imported energy, the energy intensity of the economy and the flexibility of the energy sector, i.e. the ability to reduce consumption and to switch from one source to another.

Expressing the welfare loss, in terms of impact on GDP, as a function of the price change, the formula enables the association of any price increase with a certain loss of well-being. Although energy demand appears more sensitive to further increases in price – i.e. the greater the increase in price the higher energy price elasticity – we assume that price elasticity of demand remains constant with increasing price. This allows us to plot a growing line of welfare losses as function of energy price ratio: as the energy price goes up with respect to the actual price, the negative impact on GDP increases proportionally.

The external cost associated with energy price increases depends on its expected value. This value is obtained by multiplying the monetary consequences of the accident by the probability of occurrence of the accident. Knowing that price returns are normally distributed and that, in case of natural gas, the mean is set equal to zero and the standard deviation is set based on the historical volatility, it is possible to weight any price rise, and consequently any welfare loss, with the corresponding probability.

The result is the evaluation of the expected welfare loss, that is the weighted average of all possible welfare losses. In a quantitative terms, we have:

$$Expected\ Loss = \int_0^{\infty} \left[Loss \left(\frac{\Delta P}{P} \right) \cdot Probability \left(\frac{\Delta P}{P} \right) \right] d\frac{\Delta P}{P}$$

Therefore, the expected welfare loss is the average loss that an individual exposed to the risk of price expects to bear.

5.2.2. Willingness to pay (of risk averse individuals)

The previous simple calculation of the expected external costs associated with energy price increase usually leads to an underestimation of the value of externalities because it does not consider the risk perception of individuals, assuming, on the contrary, a risk neutral population.

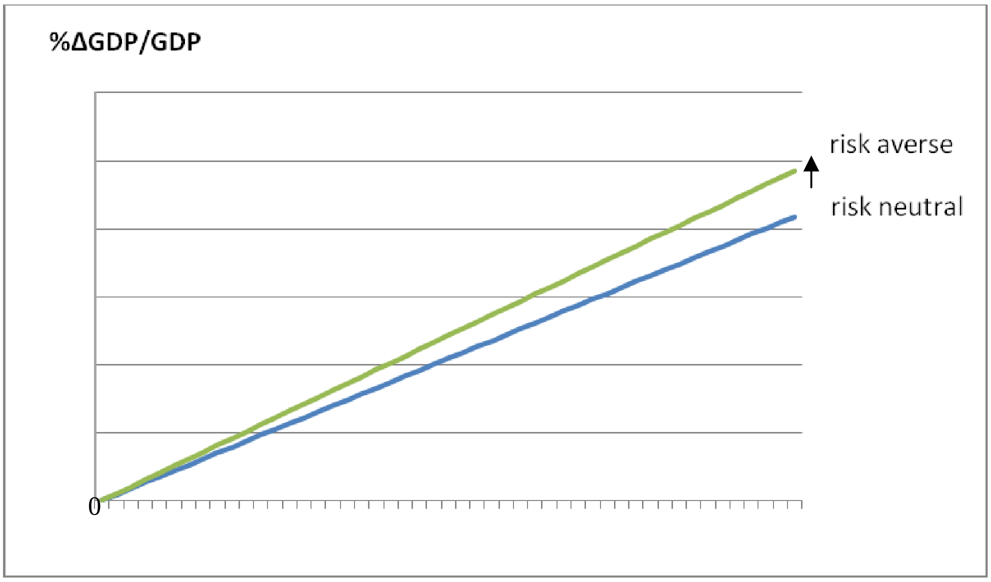
As consumers are risk averse and typically take a more cautious approach than in the hypothetical case of a risk neutral population, there is a need to integrate risk aversion within the assessment of the external costs: the expected damage, first calculated assuming risk neutrality, must take individual-risk perception into account (Eeckhoudt et al., 2000). According to our assumptions, the attitude towards risk basically depends on the country's import dependence: the higher the energy dependence the greater the country's vulnerability to energy price shocks and, therefore, the higher the perceived price increase risk.

As a result, it is possible to modify the formula of social welfare loss in order to include risk aversion, introducing a second order component so that the perceived social welfare losses rise as net import increases:

$$\% \frac{\Delta \mathrm{GDP}}{GDP} = \% \frac{\Delta \mathrm{P}}{P} * (1-\varepsilon) * \left(\frac{NI}{GDP} + \alpha \left(\frac{NI}{GDP}\right)^2 \right)$$

where α is the risk aversion coefficient: the higher α the higher economic losses.

Figure 6. Welfare loss in terms of GDP change for risk-averse and risk-neutral individuals



This new formula shows that risk averse individuals assign greater value to the potential welfare losses compared to the risk neutral one. As a result, when we take into account the individual risk perception, the curve of welfare losses, as function of energy price, is shifted upwards compared to the initial one.

Also in this case, we compute the expected welfare loss perceived by risk averse individuals, which will be higher than the one for risk neutral individuals:

$$\textit{Expected Loss with risk aversion} = \int_0^\infty \left[\textit{Perceived Loss}\left(\frac{\Delta P}{P}\right) \cdot \textit{Probability}\left(\frac{\Delta P}{P}\right) \right] d\frac{\Delta P}{P}$$

Risk averse individuals are willing to pay more to limit the potential damage incurred by society. The willingness to pay of risk averse individuals for avoiding a risky situation can be computed by comparing what would be the welfare change of a risk neutral individual with that of a risk averse one. The difference between the two welfare change represents the risk premium:

Risk premium = Expected welfare loss with risk aversion – Expected welfare loss without risk aversion

5.2.3. A tool to improve security of energy supply

The third step requires the assessment of the costs of any action that can counteract the damage to the welfare of society caused by a lack of security of supply. As previously discussed, different tools are available to prevent or mitigate the negative impacts of a sudden energy price rise. For a practical approach, we limit the analysis to hedge programmes designed to offer an insurance-type coverage bought in the financial market, to provide protection against price spikes. In particular, we restrict the use of insurance tools to call options only.

For ease of calculation, we assume that the call options are European: by purchasing a call option we acquire the right to buy a given quantity of energy on a certain date (i.e. the maturity date) at a pre-determined price (i.e. the strike price), paying the so-called option-premium. By guaranteeing that consumers will not pay more than the strike price, this hedge strategy can be described as "price cap" strategy, in which the strike price represents the maximum purchase price. Whether the call option is exercised or not depends on what the strike price is with respect to the market price at the option's maturity date. If the strike price is lower than the market price, the call option is exercised – i.e. consumers can buy energy at the strike price avoiding the higher market price. As a consequence, the benefits of call options are measured by avoided loss of GDP (the light blue area in the figure 7), due to the price pegging, which appear only when the current energy price exceeds strike price. In this case the call option is said to be "in the money".

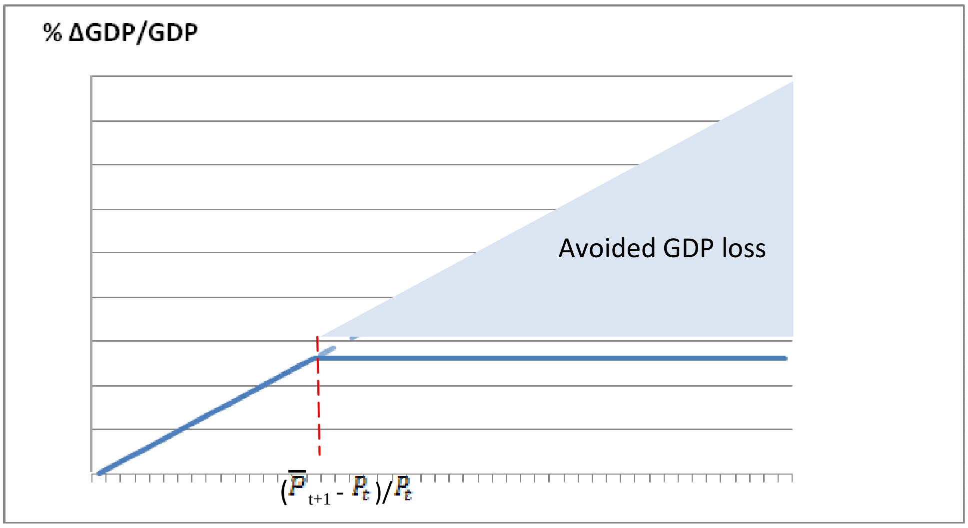
For a call option with strike price $\overline{P}_{t+1}$, we calculate the premium, C, by using the Black-Scholes (1973) formula:

$$C = P_t\, N(d_1) - \overline{P}_{t+1}\, e^{-rT}\, N(d_2)$$

where $d_1 = \dfrac{\ln\left(P_t / \overline{P}_{t+1}\right) + \left(r + \sigma^2/2\right) T}{\sigma\sqrt{T}}$ and $d_2 = d_1 - \sigma\sqrt{T}$

The current spot market price is denoted by P_t, and the risk free rate of interest by r, T is the date of expiration, σ^2 is the volatility of the spot market price and N(·) is the probability distribution function of a standard normal variable.

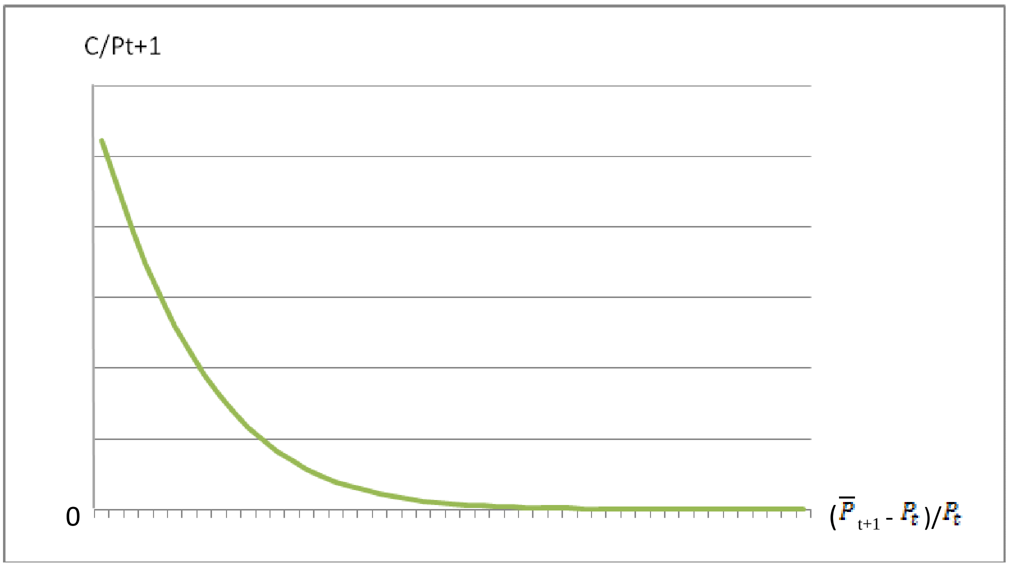
Figure 7. GDP loss with a call option at a strike price equal to $\overline{P}_{t+1}$



According to the formula, by choosing a strike price slightly above the initial spot market price allows to limit changes in energy price to small increases implying a higher level of energy security at a cost; on the contrary, the higher the strike price the lower the cost of coverage.

These considerations enable to plot a curve of the cost of insurance as a function of increasing energy strike prices ($\overline{P}_{t+1}$) with respect to the initial market price (P_t).

Figure 8. Call option premium



At what price level should the cap be set? What would be an acceptable level of price increase? How much does it cost to provide such a type of insurance? In the following section we try to answer these questions.

5.2.4. Acceptable level of security of supply

In this section we provide two alternative methods useful to derive a reasonable “penalty”, to impose on energy prices, in order to account for the price risk component.

5.2.4.1. First method: Risk premium and willingness to pay of risk averse individuals

In line with the first method, we assess the level of the price risk people are willing to bear by calculating how much they are willing to pay to ensure it. Computing the difference between the total expected damage suffered by a risk neutral individual and the total expected loss perceived by a risk averse one it is possible to quantify how much money the latter is ready to pay to avoid the potential damage caused by a price shock (i.e. the Risk Premium).

More precisely, we compute the *premium per unit of imported energy*, that is the monetary surcharge that people are willing to pay on any GJ of imported gas to hedge against price increases, as:

$$\frac{RP}{NI(1-\varepsilon)}$$

Where:

- RP is the risk premium
- NI is the gas net import (in GJ)
- ε is the gas demand elasticity to gas price (in absolute value)

Assuming that we rely only on call options as a hedge strategy, we can equalise the *call option premium* (C) – i.e. how much it costs society to restrict the extent of the price increase to an acceptable level – and the *unitary risk premium* – i.e. how much society is willing to pay to limit the price increase. This allows us to derive the maximum price increase that society is ready to accept, that is the “optimal” strike price.

5.2.4.2. Second method: setting a cap on GDP loss

The basic idea of the second approach is that society is averse to the risk of suffering heavy losses and it is ready to pay in order to limit this potential damage.

We suppose that countries may define, ex-ante, the maximum annual loss of GDP they are willing to bear because of energy price shocks. Setting a cap on GDP losses allows to calculate the maximum level of energy price increase consumers can accept and, consequently, how much they have to pay for eliminating further losses.

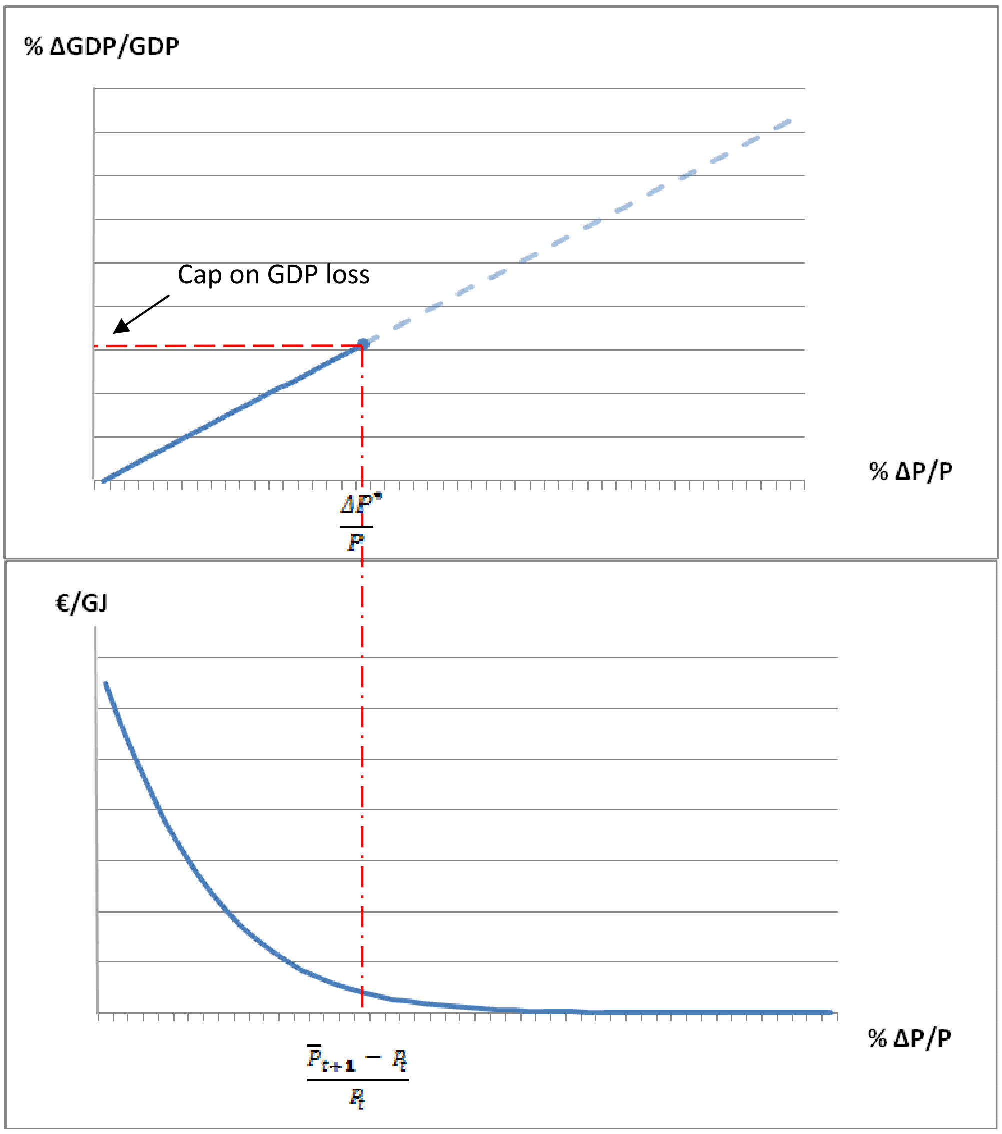
More precisely, once countries have to define a maximal threshold for the economic damage they are willing to accept ($[\Delta \mathrm{GDP}/\mathrm{GDP}]^{\uparrow *})$, through the formula in paragraph 5.2.2, we can easily evaluate the level of price increase that restricts the extend of GDP decline to the desirable level (i.e. $[\Delta P/P]^{\uparrow *})$:

$$\frac{\Delta P^*}{P} = \frac{\Delta \mathrm{GDP}^*}{\mathrm{GDP}} * [(1-\varepsilon) * (\frac{NI}{GDP} + \alpha\left(\frac{NI}{GDP}\right)^2)]^{-1}$$

The aim is to assess the cost to ensure that price does not exceed the tolerable level. In other words we need to evaluate the cost of a call option characterised by a strike price ($\overline{P}_{t+1}$) such that $\frac{\overline{P}_{t+1} - P_t}{P_t} = \frac{\Delta P^*}{P}$

A qualitative representation is provided with the following figures (9 and 10).

Figure 9-10. Cap on GDP loss


% ΔGDP/GDP
Cap on GDP loss
% ΔP/P
ΔP*/P
€/GJ
% ΔP/P
(P̄t+1 − Pt)/Pt

6. Assessing the price component: case studies

The security of supply cost (or benefit) of the project can then be valued through the levelised cost (LC) calculation, as:

$$LC = \frac{total\ discounted\ costs\ to\ comply\ with\ the\ standard}{total\ discounted\ energy\ supplied\ by\ the\ project} + hedging\ price\ increase\ cost$$

While the first component is closely related with the infrastructure under consideration, the second component depends on the country's exposure to price increase risk, so that it can be computed regardless of the project being appraised.

6.1. Physical availability component

As illustrated in paragraph 5.1.1, there are currently nine Member States that do not meet the N-1 standard. These countries have different characteristics and could bring a variety of security of supply measure to bear. For instance, Hungary is landlocked; the incremental levelised cost (capital and operational expenditures) of bringing in gas from an alternative source such as the Nabucco, is estimated at 2.75 EUR/GJ. For countries that have access to the sea, a new LNG terminal providing the needed capacity would have levelised costs of 0.60 to 1.50 EUR/GJ.

6.2. Pricing component

In this section we apply the methodology provided for the assessment of the pricing component to the case of natural gas for a set of countries (Germany, Spain, Italy, United Kingdom and Poland).

For the assessment of the welfare loss we set the initial price equal to Pt and simulate progressive infinitesimal price rises, starting with the case in which the energy price remains the same after one year ($\Delta P=0$). We use equation (10) and set a range of hypothesises:

- $P_t = 6,2$ €/GJ
- $\varepsilon = 0,14$ and it remains constant over time and as price goes up
- t=1 year

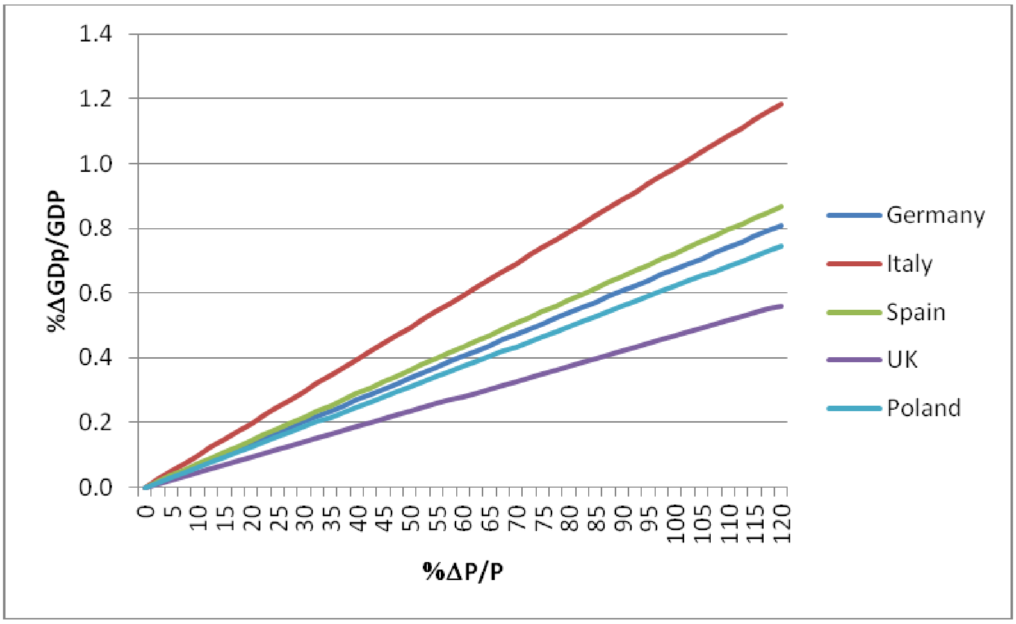
All the data are provided by IEA database and refer to 2009 values.

Table 5. Germany, Spain, Italy and United Kingdom data

	unit	Germany	Italy	Spain	UK	Poland
Net imports (NI)	PJ	3,128	2,865	1,440	1,487	413
Total consumption	PJ	3,619	3,162	1,450	3,925	595
P_t	€/GJ	6.2				
GDP	€bn	2,477	1,549	1,063	1,696	355

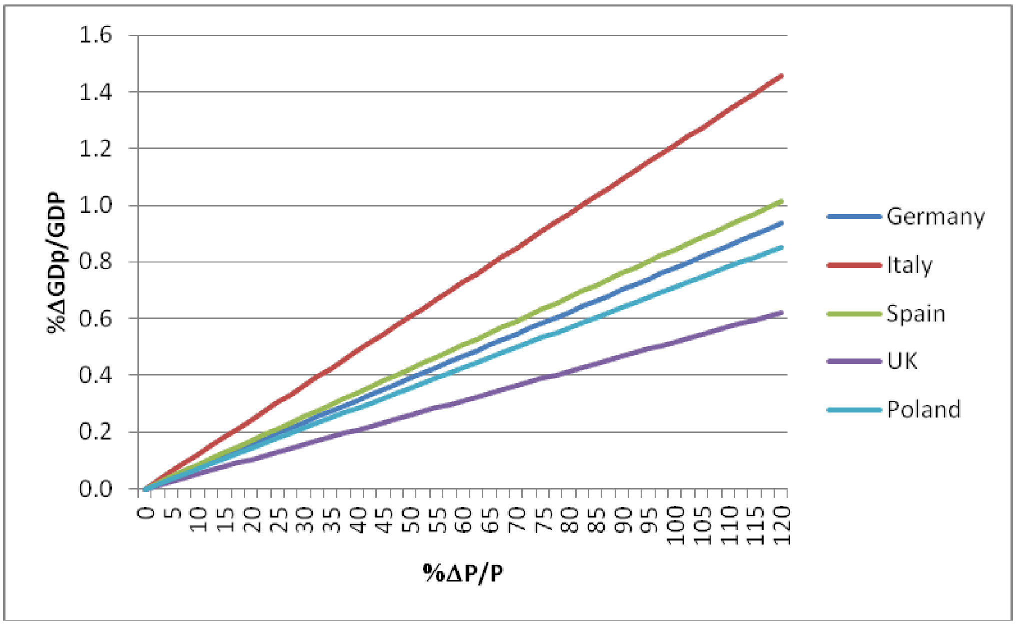
Elasticity		0.14				
NI*Pt-1	€bn	19.4	17.8	8.9	9.2	2.6
NI*Pt-1/GDP	%	0.78	1.15	0.84	0.54	0.72

Figure 11. Impact of energy price increase on GDP with risk neutrality



As figure 11 shows, the impact of natural gas price increase on GDP, is proportional to countries' vulnerability level, which in turn is a function of the degree of gas imports. In order to include risk aversion behaviour, we use equation (12) with a risk aversion coefficient α equal to 20 (Eeckhoudt et al., 2000).

Figure 12. Impact of energy price increase on GDP with risk aversion



Equations (11) and (13) allow us to derive the expected welfare loss for a risk-neutral and a risk-averse individual respectively. The difference between the two expected values gives the risk premium.

All these calculations are summarised in Table 6, where the last row reports the monetary surcharge that people are willing to pay on any GJ of imported gas to hedge against price increases.

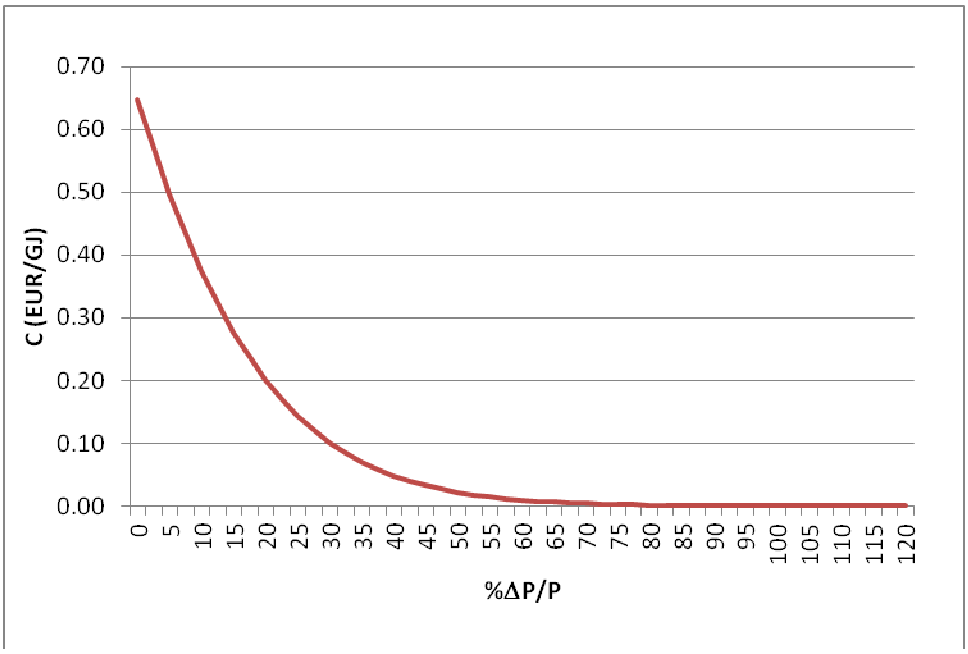
Table 6. Risk Premium

		Germany	**Italy**	**Spain**	**UK**
A	Expected loss with risk neutrality (%)	0,055	0,076	0,058	0,031
B	Expected loss with risk aversion (%)	0,064	0,089	0,067	0,034
B-A	RISK PREMIUM (%)	0,00898	0,0158	0,00978	0,0028
RP=(B-A)*GDP	RISK PREMIUM (€)	215362992	240608598	103163659	44417397
RP/[NI*(1-ε)]	UNITARY RISK PREMIUM(€/GJ)	0,07999	0,10619	0,0835	0,0450

For the assessment of the cost of coverage, starting from the general formula of option premium provided by Black and Scholes, we assume that:

- P_t = 6,2 €/GJ
- $r = 0.05$
- $\sigma = 0.2$
- $T = 1$ year

Figure 13. Call option premium



As these assumptions are the same for all countries, the costs of the hedge programme are equal for all of them.

In line with the first method, we can derive the maximum price increase that individuals are willing to pay by equating the call option premium (C) and the unitary risk premium.

Figure 14. Maximum price increase: first method

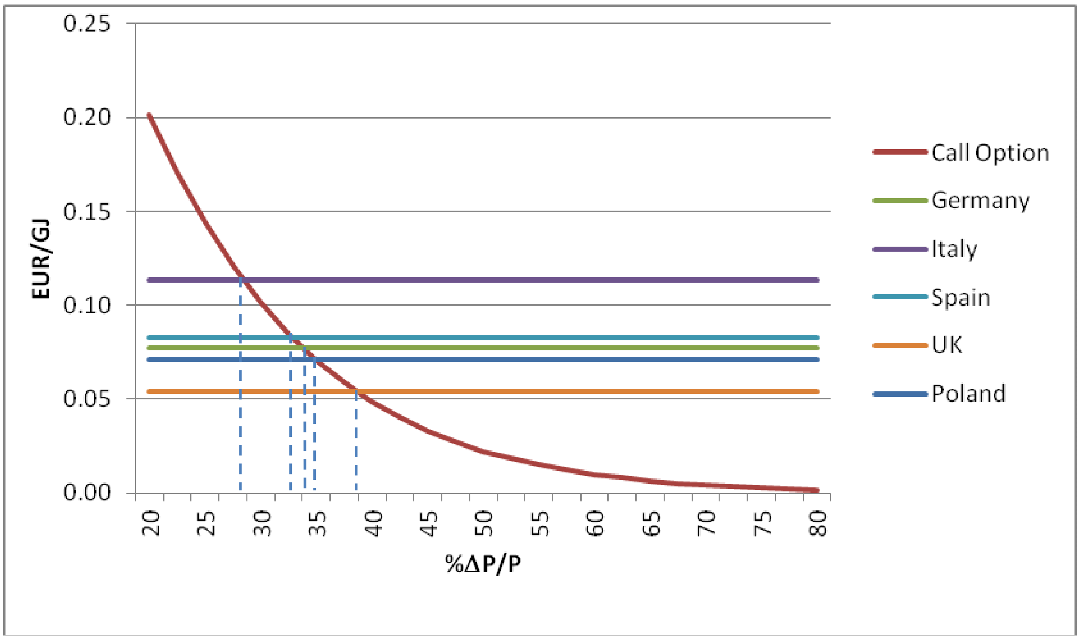


Table 7. Maximum price increase that each country is ready to accept

Germany	Italy	Spain	UK	Poland
~34%	~28%	~33%	~39%	~35%

Table 8. Cost of call option (€/GJ): first method

Germany	Italy	Spain	UK	Poland
0.08	0.11	0.08	0.05	0.07

In line with the second method, countries can set a cap on GDP loss. For instance, a reasonable value could be an annual decline in GDP due to price rises of around 0.3% (IEA, World Energy Outlook 2006).

In order to limit the annual GDP loss due to natural gas price increase to 0.3%, each country has to guarantee that the gas price does not exceed a given level (i.e. around 25% for Italy, between 35% and 40% for Germany and Spain, above 40% for Poland and 60% for UK) through the purchase of call options. The call option premium values, that have to be applied to the energy price, are provided in Table 10.

Figure 15. Maximum price increase: second method

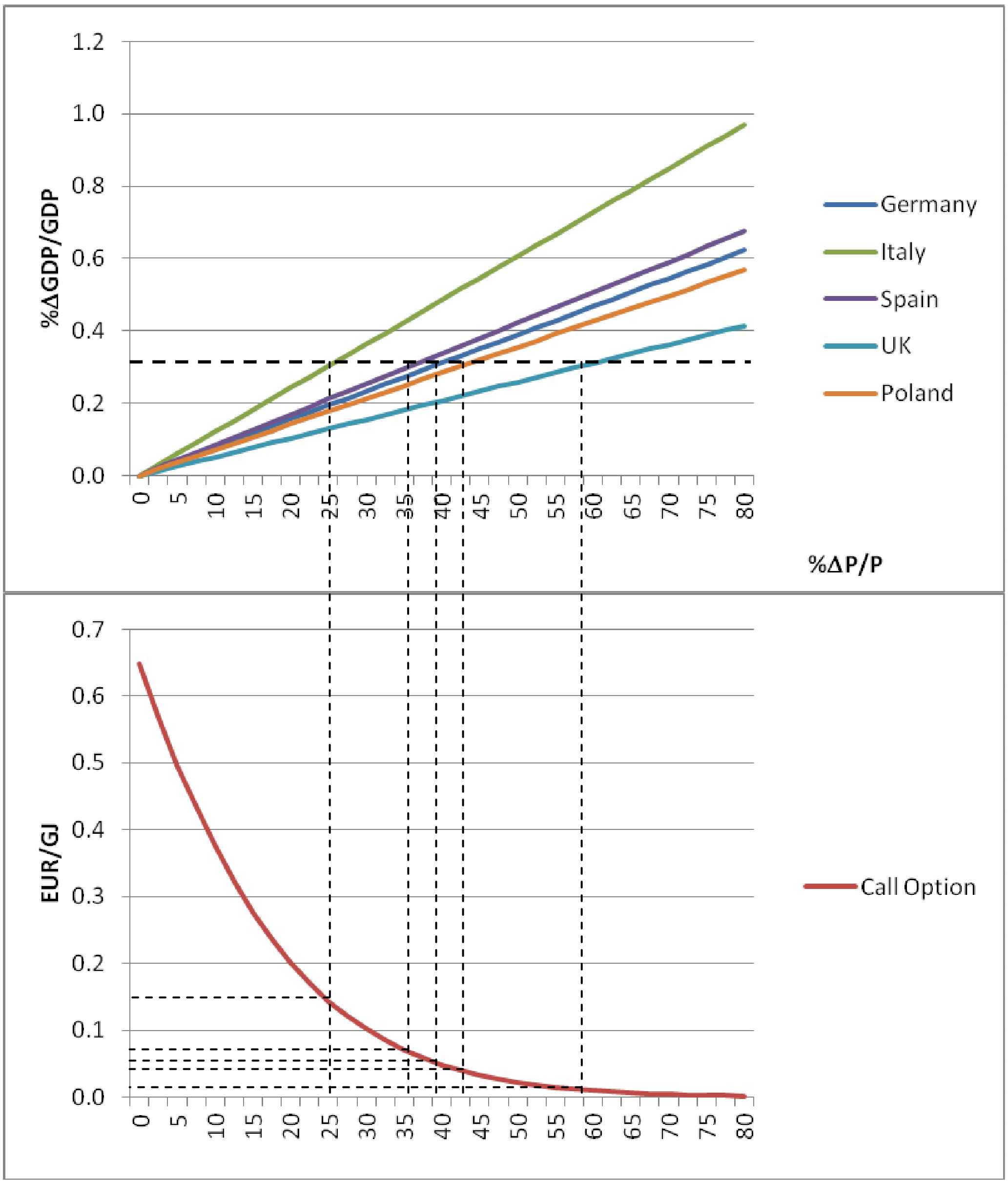


Table 9. Maximum price increase that each country is ready to accept

Germany	Italy	Spain	UK	Poland
~40%	~25%	~35%	~59%	~43%

Table 10. Cost of call option (€/GJ): second method

Germany	Italy	Spain	UK	Poland
0.06	0.15	0.08	0.01	0.05

6.3. Cost of security of supply

Overall, the value of the security of supply externality associated with natural gas is estimated in the range 0.1 EUR/GJ to 2.2 EUR/GJ (it would go up to 2.9 EUR/GJ considering the costs for the Nabucco pipeline).

This translates into a security of supply “penalty” applicable to the levelised costs of electricity generation from natural gas ranging from less than 1 EUR/MWh (in case the physical availability component is nil) to 14 EUR/MWh (in case the physical availability component is at the maximum) or even 20 EUR/MWh (assuming security will be provided by the Nabucco pipeline).

7. Conclusions

Although economists agree about the nature of energy security costs and concur with the need to internalise them in final energy prices, academic literature does not provide a practical solution for assessing these external security costs. In this regard, the paper contributes by presenting a method to evaluate the externalities associated with security of energy supply and what has to be done to internalise them, taking into account the two main constituent parts of energy security: physical availability and pricing. Although energy prices and quantities are related to each other, we can separate the means of dealing with a cut in supplies from those to limit price volatility.

Our assessment leads to three important conclusions. Firstly, an empirical analysis of the two factors of energy security highlights that the physical component is significantly larger (1 order of magnitude) than the pricing component. In other words, a country needs to spend much more to differentiate the supply infrastructures than to hedge price volatility. Countries that have in place an adequately diversified infrastructure are less subject to security issues than countries that are not fulfilling the N-1 standard requirements; the latter will have to pay a much larger cost in order to internalise the energy security externality.

Secondly, the issue of security of supply is a specific rather than general problem. Some EU Member States have already internalised the externalities, to various degrees and at different costs, while others are not hedged against the possibility of a significant supply disruption or price spike. The cost for the full internalisation of the energy security externality depends highly on a country's characteristic and may vary significantly among countries or projects.

Thirdly, as regards fossil resources, we must differentiate the international energy markets where it is easy to change the origin or destination of trade of energy sources from those in which the link between supplier and buyer is more rigid. The coal market is the least developed in terms of international trade, and also raises less concern given the abundance of raw material and the limited role of states in the production and trade. As a result, the physical component of supply security can be considered negligible.

The oil market is a true interconnected international market, but raises concerns about the presence of political factors that may cause the disruption of not negligible amounts of production in a short time. This explains why importing countries have established common policies to cope with supply disruptions for more than forty years. Looking at past experience (stocks have been used only three times and in no case was oil consumption rationed) it seems that the current stockholding policy has adequately internalised the risk of supply disruption.

Trade in gas is much more rigid (i.e. more contract-specific) when the exchanges are made through pipelines and the risk of disruption increases when there are transit countries. The fact that for gas the risk is contract-specific means that each project could increase or decrease the security of supply. The N-1 rule in this case has been introduced by the EU; in the evaluation of gas import projects we should take into account the costs associated with compliance with the N-1 rule. Our preliminary analysis shows that this cost may be quite high and in any case higher than in the case of coal and oil import. Therefore, among fossil resources, natural gas is the fuel that presents by far the highest costs of supply security.

Our analysis could be further refined, in particular as regards the modelling of: 1) consumers' risk aversion; 2) welfare loss (with a non-linear approach); 3) probability of supply disruption; and 4) price volatility. We offer this as a possible avenue for future research.

8. References

8.1. Articles

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